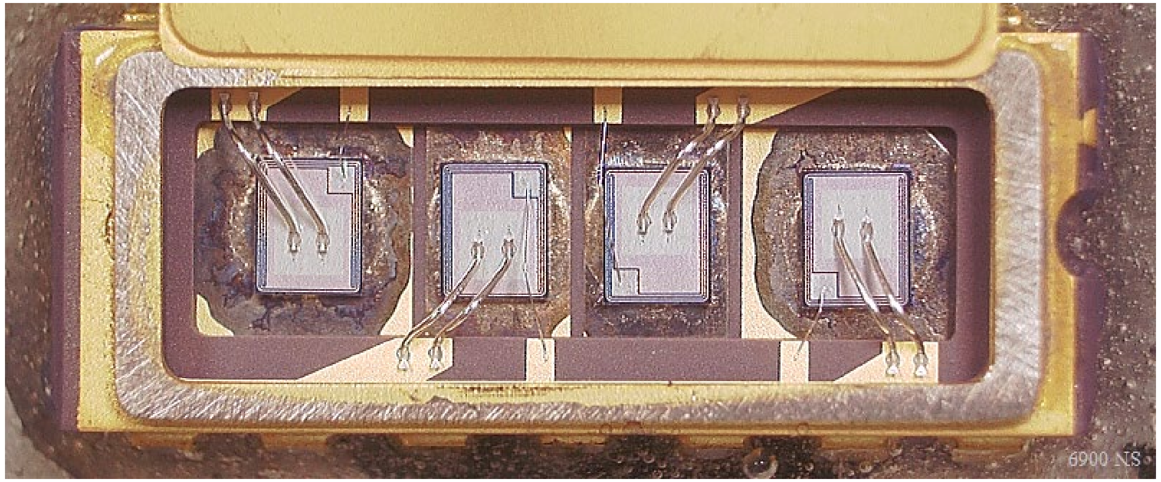
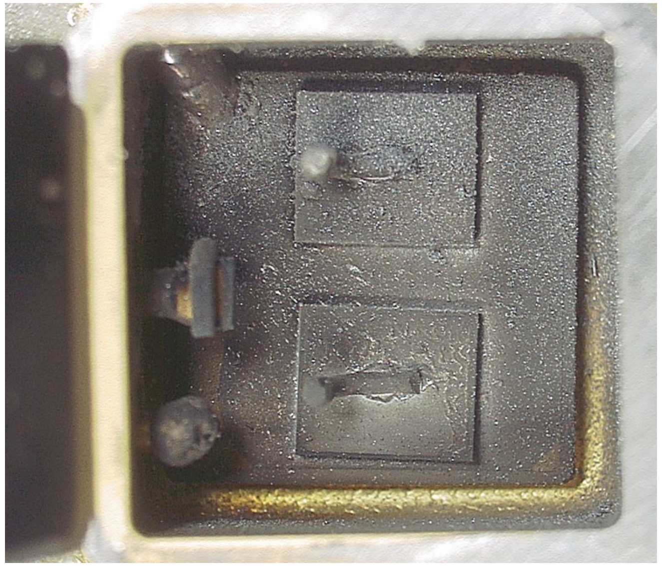
# NASA GSFC EEE Parts: DPA and FA Summary

Destructive Physical Analysis



Failure Analysis



Lyudmyla Ochs
Failure Analysis Engineer
NASA GSFC Code 562 EEE Parts, Photonics and Assembly Branch
June 16, 2022

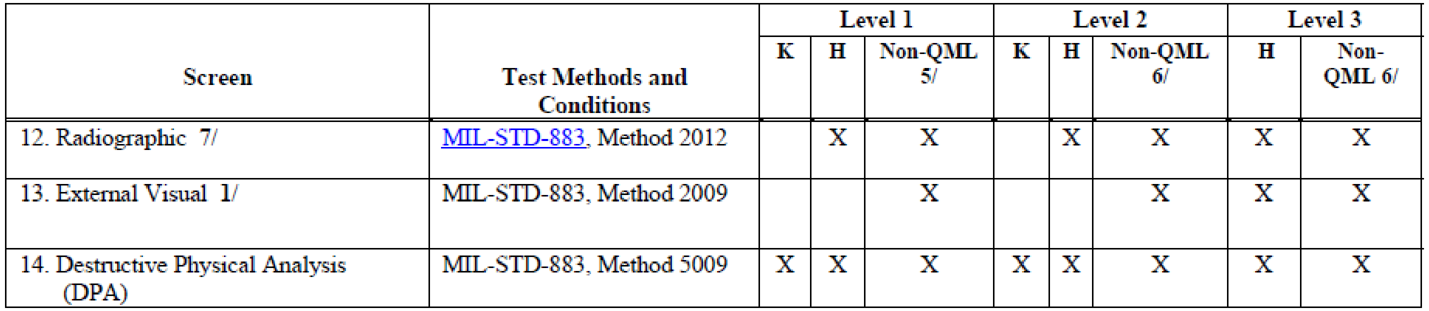
# Acronyms

| | |
|---|---|
| CSAM | C-Mode Scanning Acoustic Microscopy |
| DPA | Destructive Physical Analysis |
| EOS | Electrical Over Stress |
| EEE Parts | Electrical, Electronic and Electromechanical Parts |
| ESD | Electro Static Discharge |
| FA | Failure Analysis |
| GSFC | Goddard Space Flight Center |
| IGA | Internal Gas Analysis |
| NASA | National Aeronautics and Space Administration |
| PIND | Particle Impact Noise Detection |
| PEM | Plastic Encapsulated Microcircuit |
| PMA | Prohibited Materials Analysis |

# Selection of Parts for DPA

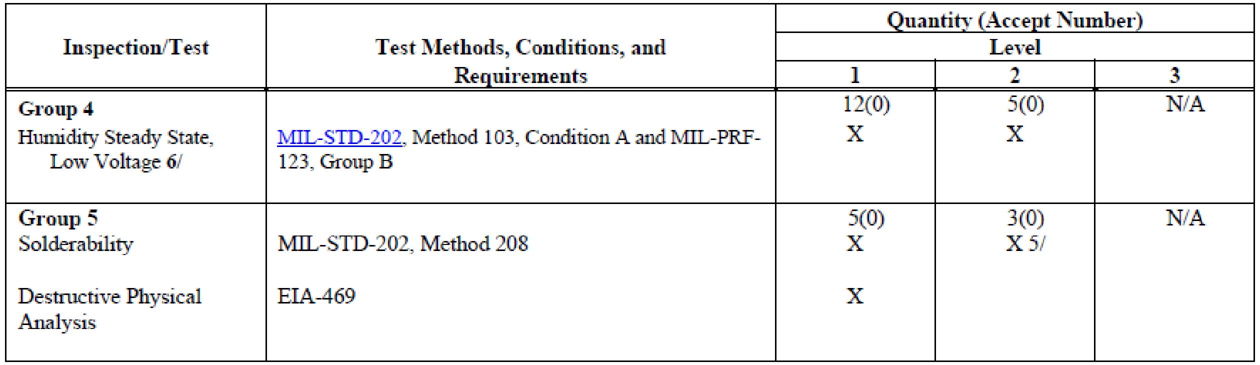
- NASA GSFC projects follow EEE-INST-002 for selection and testing of EEE parts
- EEE-INST-002 defines when DPA should be performed based on combination of factors that includes commodity type, quality level of part type selected and project level (risk tolerance)

**Table 2 SCREENING REQUIREMENTS FOR HYBRID MICROCIRCUITS (Page 2 of 2)**



| Screen | Test Methods and Conditions | Level 1 | | | Level 2 | | | Level 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | K | H | Non-QML 5/ | K | H | Non-QML 6/ | H | Non-QML 6/ |
| 12. Radiographic 7/ | MIL-STD-883, Method 2012 | | X | X | | X | X | X | X |
| 13. External Visual 1/ | MIL-STD-883, Method 2009 | | | X | | | X | X | X |
| 14. Destructive Physical Analysis (DPA) | MIL-STD-883, Method 5009 | X | X | X | X | X | X | X | X |

**Table 3A CERAMIC CAPACITOR QUALIFICATION REQUIREMENTS 1/ (Page 2 of 3)**



| Inspection/Test | Test Methods, Conditions, and Requirements | Quantity (Accept Number) | | |
|---|---|---|---|---|
| | | Level | | |
| | | 1 | 2 | 3 |
| **Group 4**<br>Humidity Steady State, Low Voltage 6/ | MIL-STD-202, Method 103, Condition A and MIL-PRF-123, Group B | 12(0)<br>X | 5(0)<br>X | N/A |
| **Group 5**<br>Solderability | MIL-STD-202, Method 208 | 5(0)<br>X | 3(0)<br>X 5/ | N/A |
| Destructive Physical Analysis | EIA-469 | X | | |

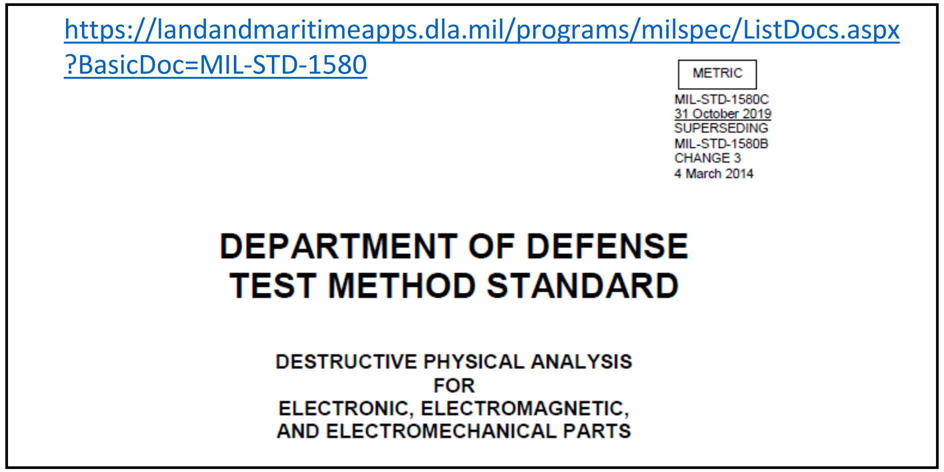
# About S-311-M-70

- DPA commonly performed per MIL-STD-1580:

  Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts

- NASA GSFC uses an internal S-311-M-70 document based on MIL-STD-1580 with several amendments:
  - Sample size
  - Prohibited Materials Analysis (PMA)
  - Capacitors
  - Ferrite beads

https://landandmaritimeapps.dla.mil/programs/milspec/ListDocs.aspx?BasicDoc=MIL-STD-1580



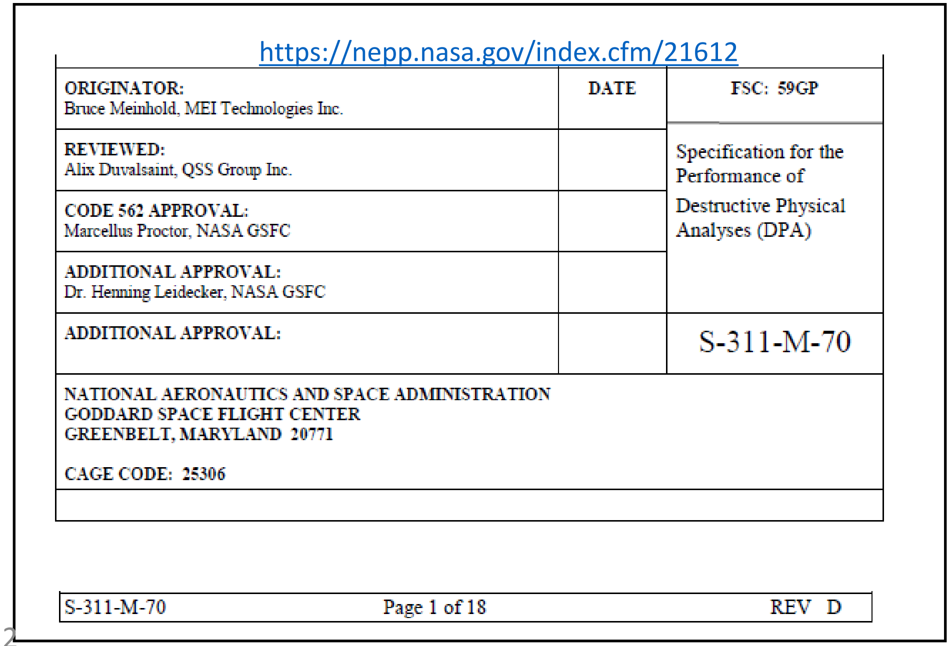
METRIC

MIL-STD-1580C
31 October 2019
SUPERSEDING
MIL-STD-1580B
CHANGE 3
4 March 2014

**DEPARTMENT OF DEFENSE**
**TEST METHOD STANDARD**

**DESTRUCTIVE PHYSICAL ANALYSIS**
**FOR**
**ELECTRONIC, ELECTROMAGNETIC,**
**AND ELECTROMECHANICAL PARTS**

https://nepp.nasa.gov/index.cfm/21612

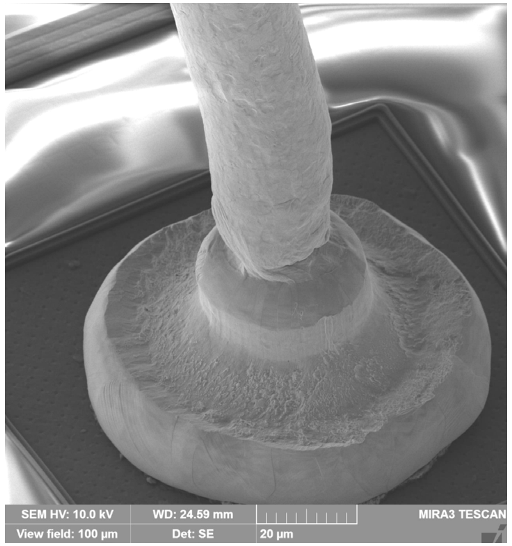


| | | |
|---|---|---|
| ORIGINATOR:<br>Bruce Meinhold, MEI Technologies Inc. | DATE | FSC: 59GP |
| REVIEWED:<br>Alix Duvalsaint, QSS Group Inc. | | Specification for the Performance of<br>Destructive Physical Analyses (DPA) |
| CODE 562 APPROVAL:<br>Marcellus Proctor, NASA GSFC | | |
| ADDITIONAL APPROVAL:<br>Dr. Henning Leidecker, NASA GSFC | | |
| ADDITIONAL APPROVAL: | | S-311-M-70 |
| NATIONAL AERONAUTICS AND SPACE ADMINISTRATION<br>GODDARD SPACE FLIGHT CENTER<br>GREENBELT, MARYLAND 20771<br>CAGE CODE: 25306 | | |

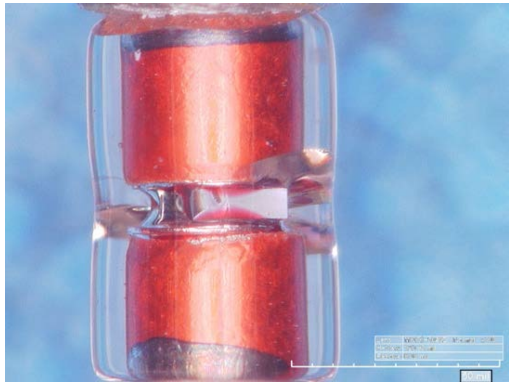
| | | |
|---|---|---|
| S-311-M-70 | Page 1 of 18 | REV D |

# Tests Most Commonly Performed During DPA

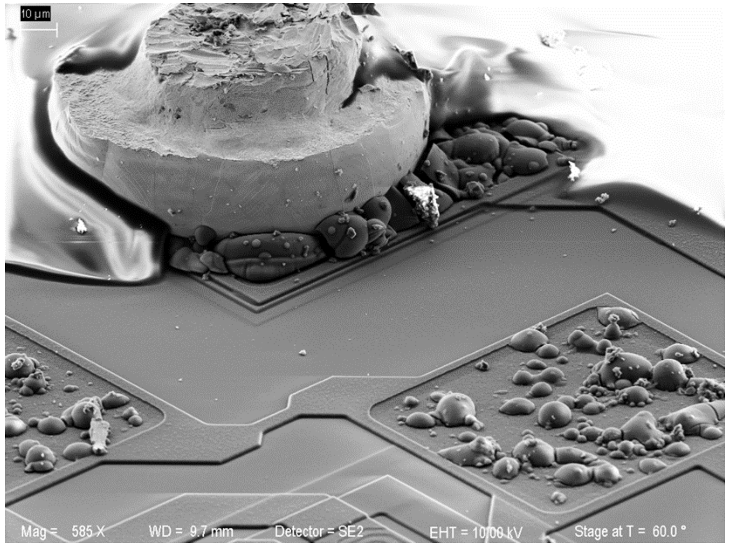
- External Visual
- External Prohibited Materials Analysis (PMA)
- X-Ray
- PIND
- Hermeticity
- Internal Gas Analysis (IGA)
- Internal Visual
- Wire Pull
- Die Shear



Wire necking above the gold ball bond – reduced wire pull strength



Gross Leak failure of diode – red dye penetrated through a crack to the die

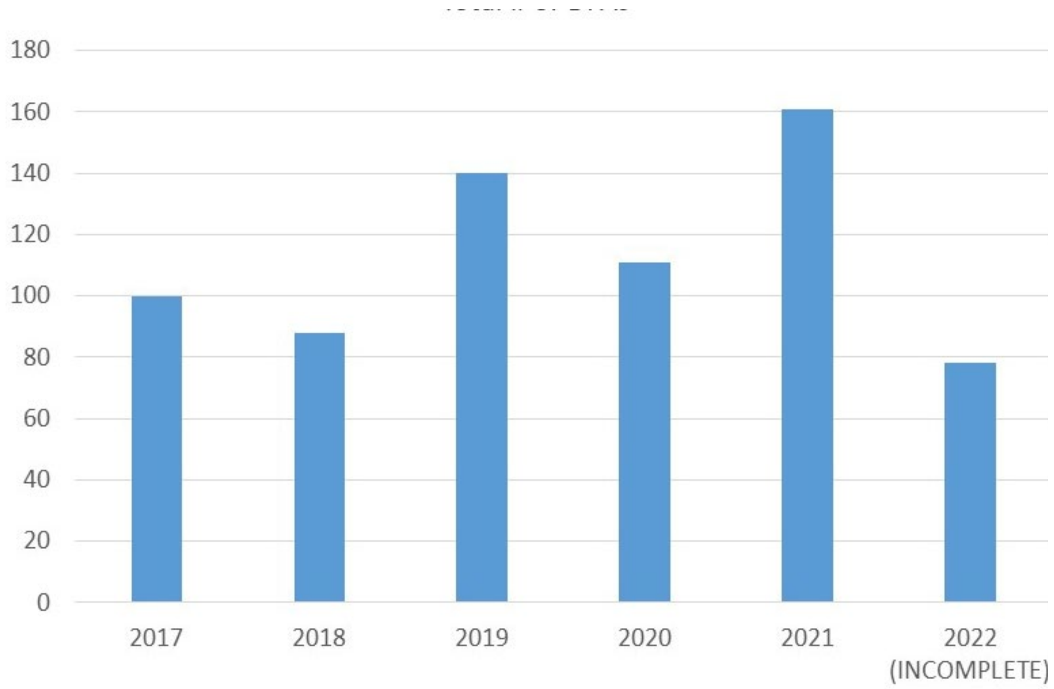


Corrosion of aluminum pad due to moisture ingress and elevated temperature exposure during screening

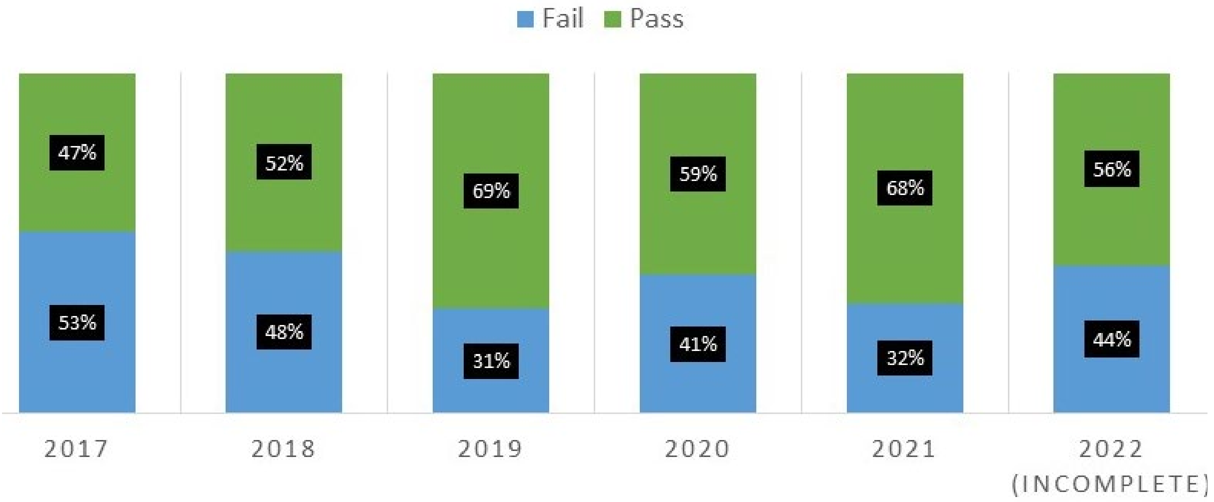
# Statistics of DPAs for 2017-2022*

(*) stats for 2022 are incomplete

## Total number of DPAs per year



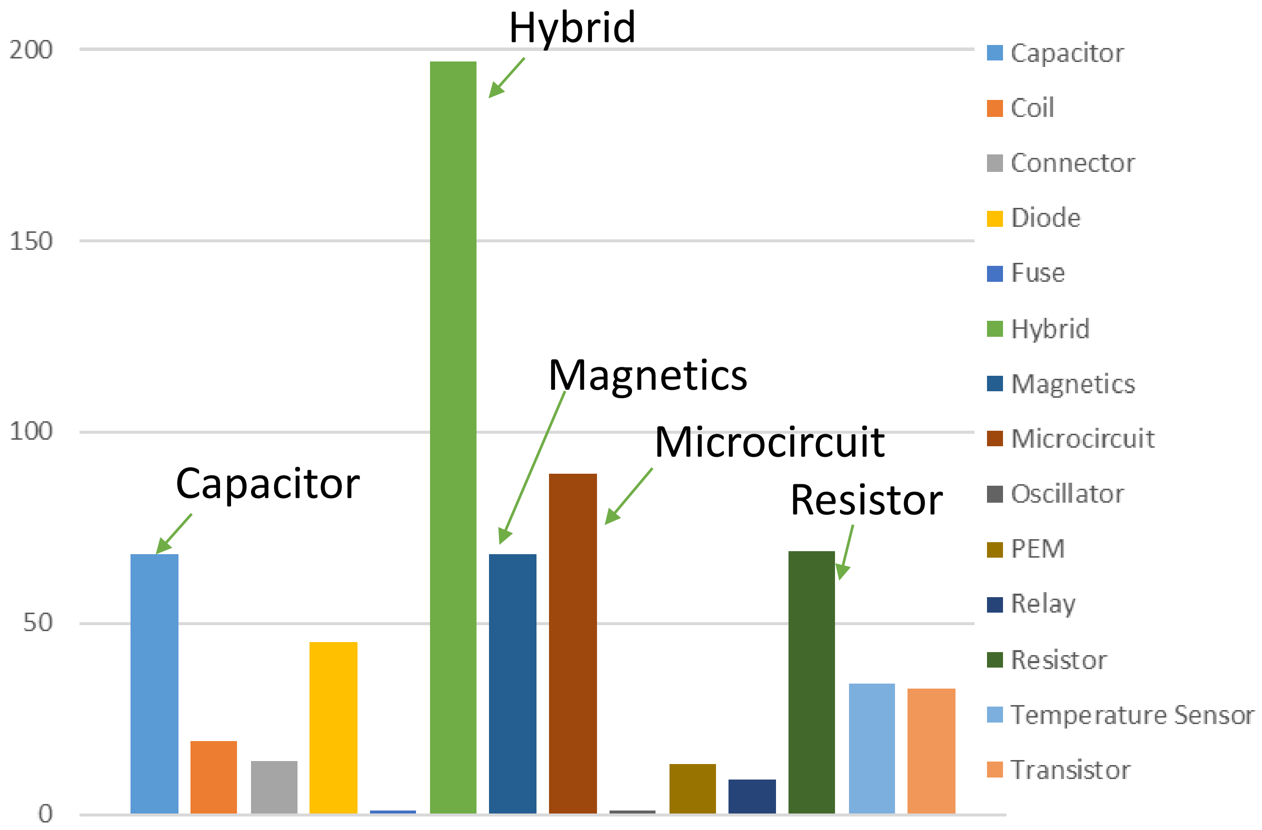
## Overall DPA Failure Rate



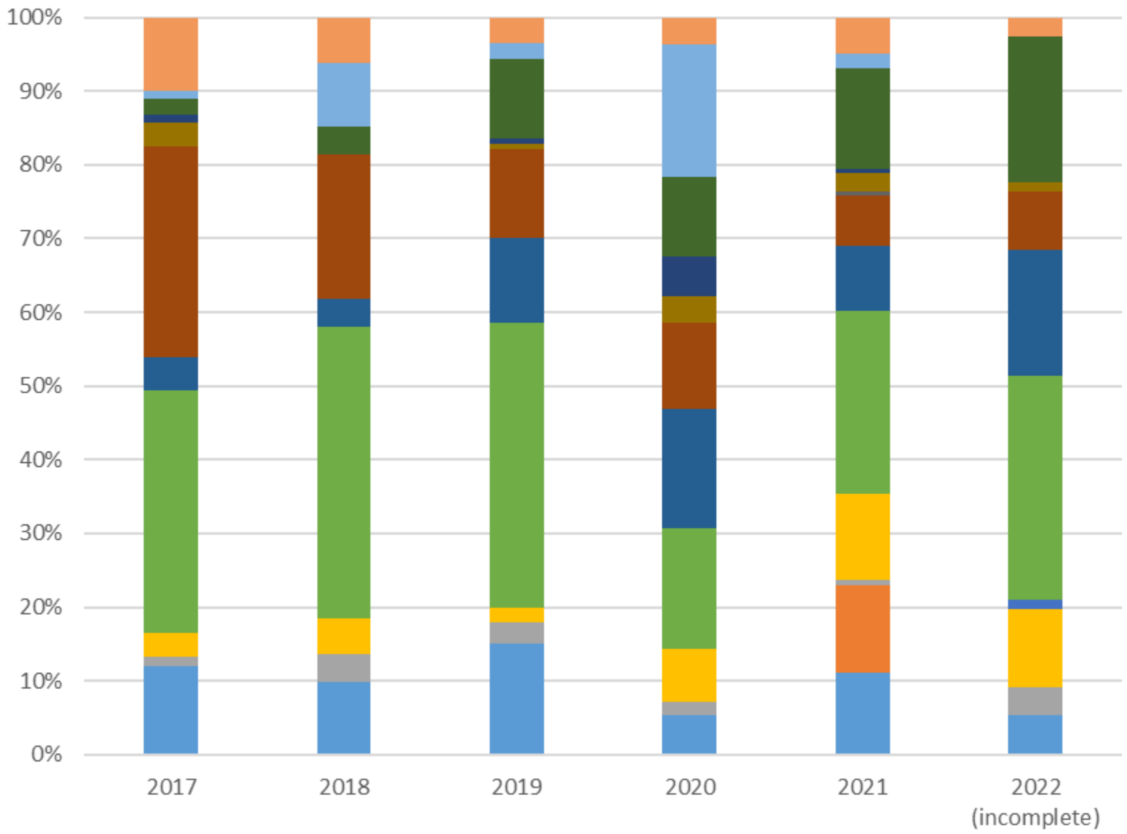
# What Parts Are DPAed?

(*) stats for 2022 are incomplete

**DPAs by Part Type**
**(2017-2022 Lumped)**



**DPAs by Part Type**
**(by year)**

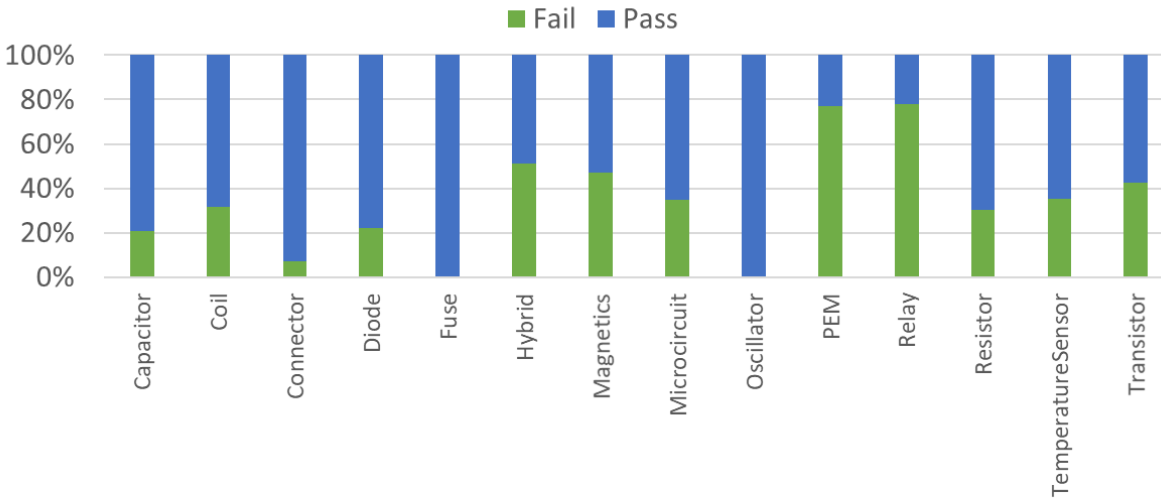


# Failure Rate by Part Type 2017-2022*

(*) stats for 2022 are incomplete

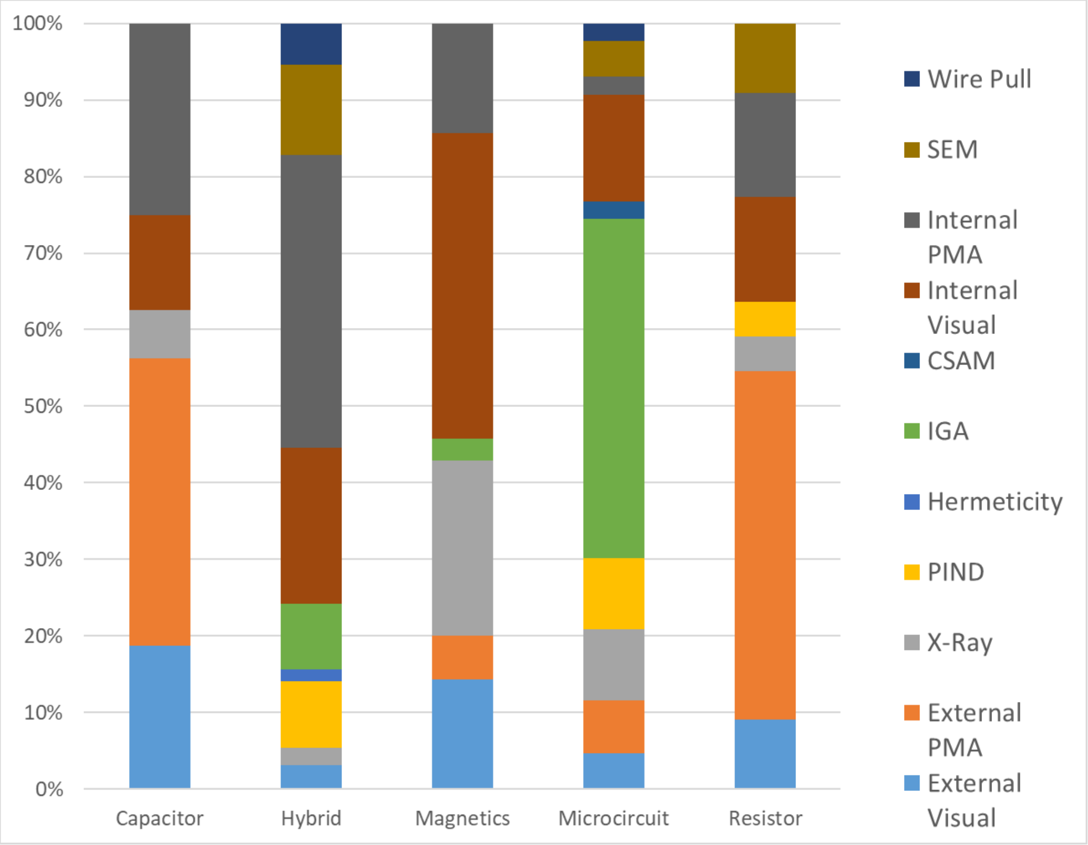
## DPA Failure Rate by Part Type

## (2017-2022 Lumped)



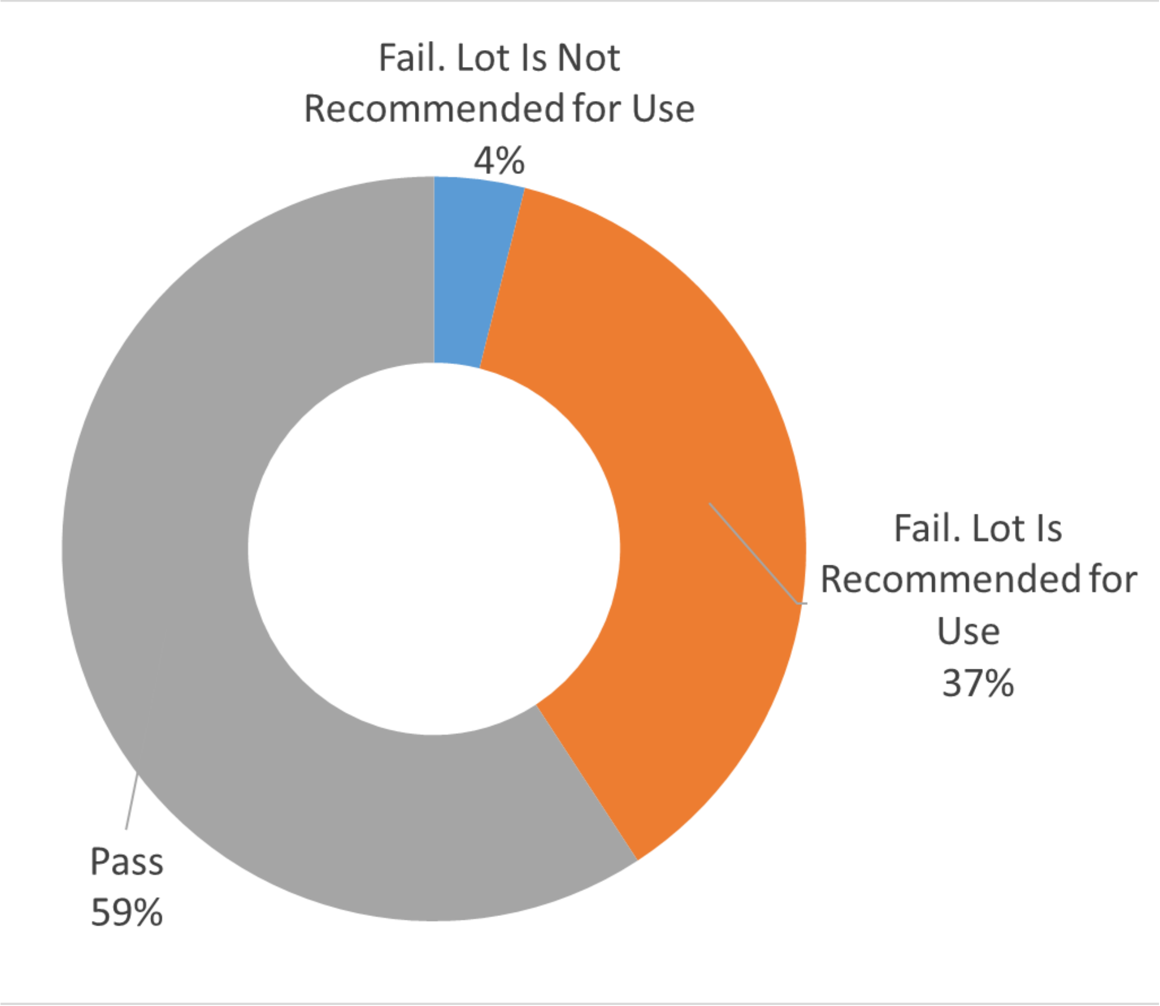
## Breakdown of DPA Failures within a Part Type by Test Type

## (2017-2022 Lumped)



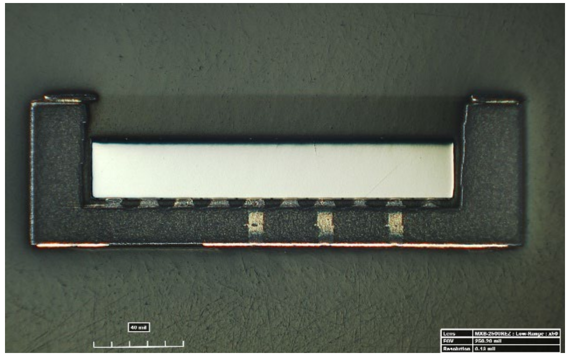
# Disposition of DPAs for 2017-2022*

(*) stats for 2022 are incomplete

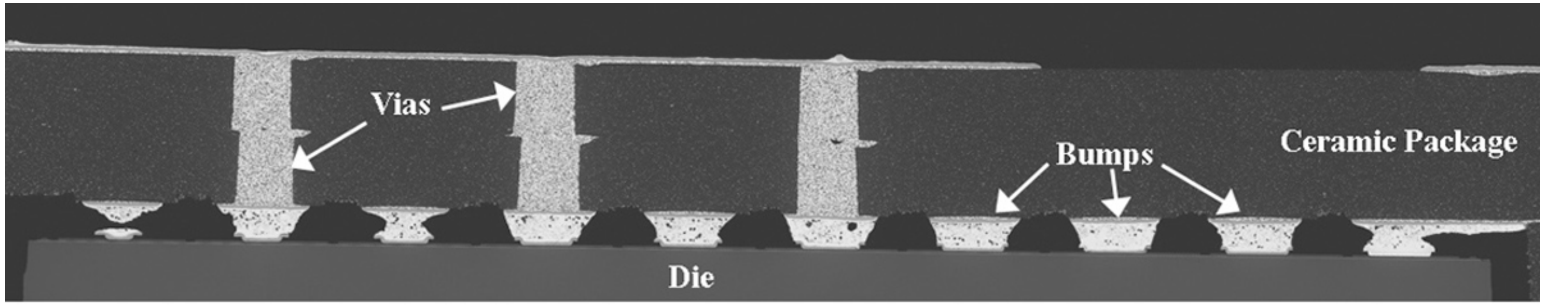


- DPA failures per S-311-M-70 (based on MIL-STD-1580) are dispositioned by a GSFC Parts Group's Failure Review Board to assess risk to the flight project
- Through review of data and/or performing additional testing, a lot may be deemed acceptable for use
- Examples of lots that failed DPA but were accepted for use
  - Failure of a transistor for external prohibited materials analysis (PMA) accepted as-is after solder dip is performed on the entire lot
  - Failure of a hybrid for internal prohibited materials analysis (PMA) accepted as-is for some vendors with known use of Pb-free materials inside the part
  - Failure of a hybrid for Internal Gas Analysis (IGA) accepted for use-as-is, even though some parts during show signs of air ingress and non-hermeticity. Mission is a short-duration Class D, does not plan on re-purchasing parts and is planning to accept risk

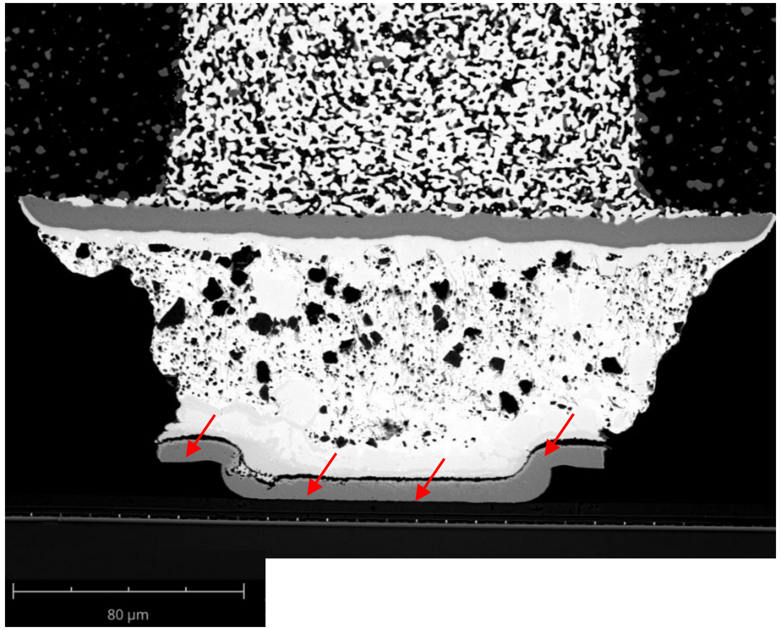
# Examples of failures during DPA that were not recommended for use



*Optical view of device in cross-section*



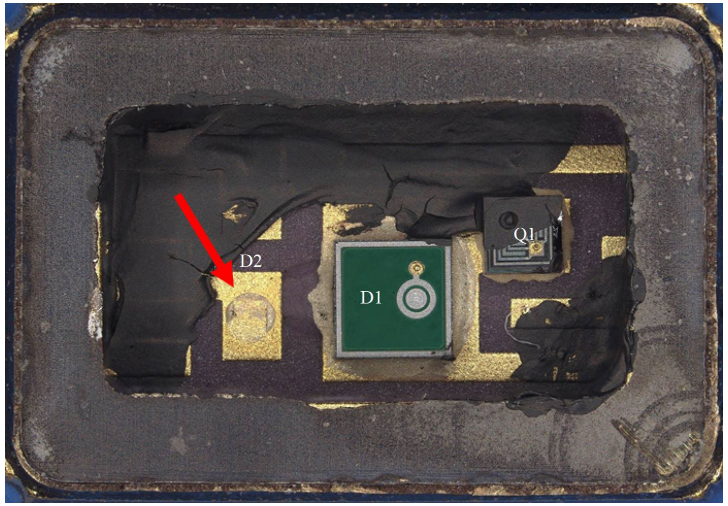
*SEM view of device in cross-section, focusing on package and underbumps*



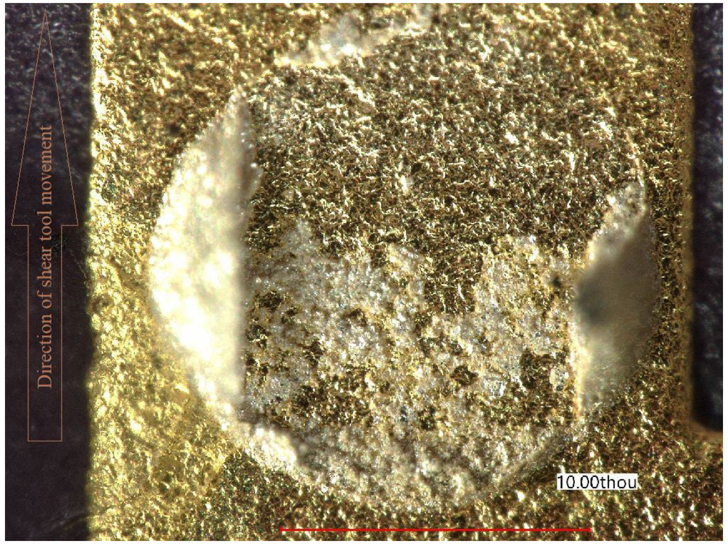
*SEM view of underbump with a separation along the Au-Sn intermetallics*

- Part:
  - Commercial microcircuit inside a hermetic package
- DPA failure:
  - Observed  Au-Sn intermetallics along both sides of the solder bump
  - Some bumps showed a separation of solder bump along the intermetallics
  - Parts were solder dipped in an uncontrolled manner by user, which may have contributed to the separation
- Disposition:
  - Not recommended for flight use
  - Attention should be paid to presence of Au-Sn intermetallics in future lots

# Examples of failures during DPA that were not recommended for use



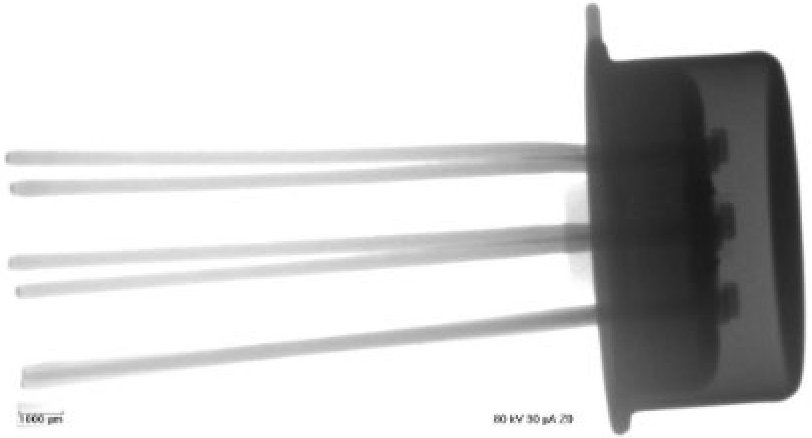
*Optical view of delided device after die shear. Missing D2*



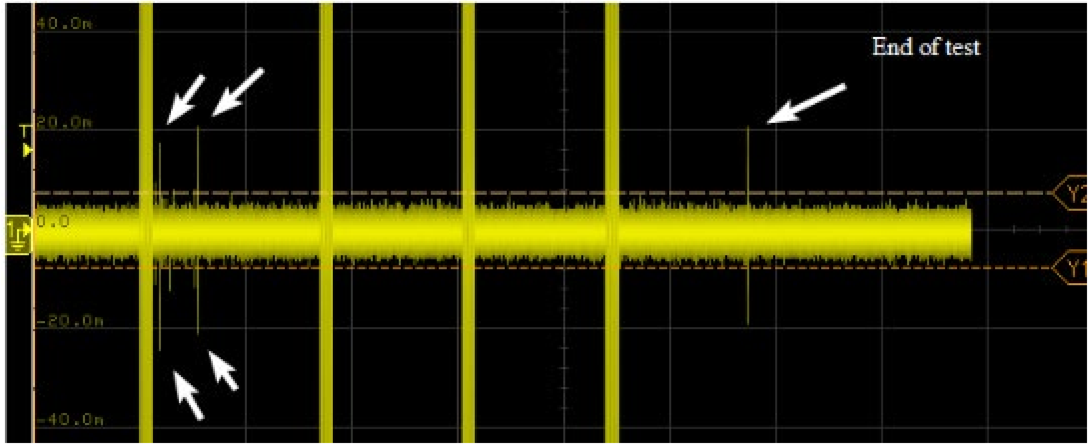
*Close-up view of the epoxy with D2 sheared off at 0g-f*

- Part:
  - Optocouplers in hermetic ceramic package
  - Parts are commercial with JANS-like screening
- DPA failure:
  - 1/5 submitted to die shear exhibited the LED die failing below the 1X limits
  - Tester indicated that die was moving as soon as shear tool made contact and measured result is invalid
  - LED die must be chemically exposed from the light pipe material, which may have resulted in damage to the bonding characteristics. The other four devices exhibited LED shear levels slightly above the 2X limit, and were all in family
- Disposition:
  - Not recommended for flight use
  - Project has designed part out of the system. Lot may be usable in future applications but will require evaluation of the DPA results

# Examples of failures during DPA that were recommended for use



*X-Ray overview of the transistor package*

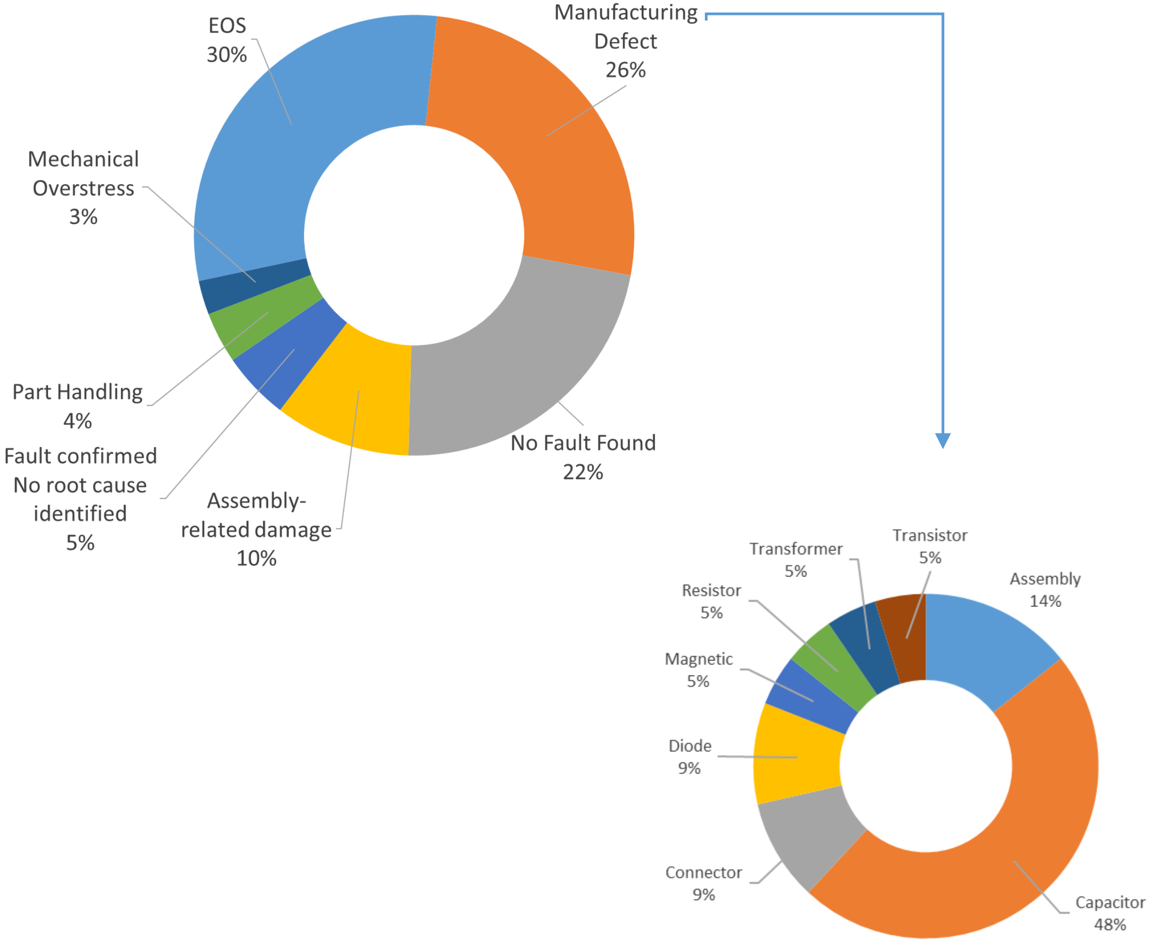


*PIND scope recording of failure*

- Part:
  - Transistors in TO-can packages
  - Part is commercial, rad-hard, manufactured on MIL-PRF-38535 Level V (with modification)
- DPA failure:
  - 1/3 failed for Particle Impact Noise Detection (PIND)
  - Particle capture attempted, but unsuccessful
- Disposition:
  - Remainder of the lot subjected to PIND with no failures
  - Recommended use-as-is due successful completion of PIND

# Statistics of FAs for 2017-2022*

(*) stats for 2022 are incomplete

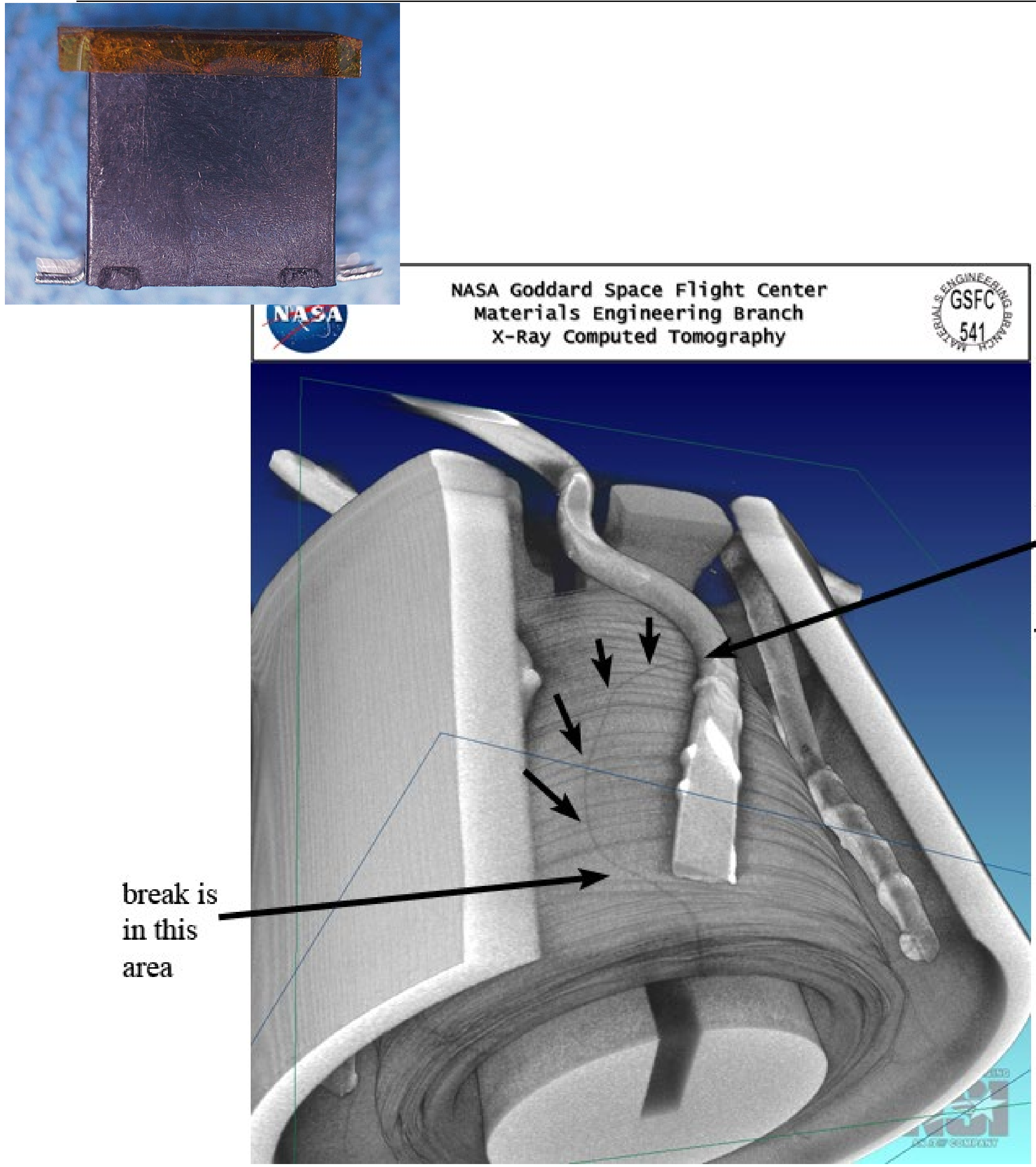


*Breakdown of FA conclusions*

*Manufacturing Defects: Breakdown by Part Types*

- Perform 10-20 failure analyses (FA) a year, mostly for NASA GSFC projects
- FA is usually requested when EEE part has been identified as suspect or faulty during assembly inspection or testing
- Most common EEE parts submitted for FA:
  - Microcircuits - 22%
  - Capacitors - 25%
  - Hybrids - 10%
- Most common failure categories:
  - Electrical Over Stress (EOS) – 30%
  - Manufacturing Defects – 26%
    - Most devices with manufacturing defects that come to FA are capacitors
    - No FAs with manufacturing defects seen in microcircuits or hybrids seen

# FA example: Manufacturing Defect



- Part:
  - Commercial transformer used on engineering (non-flight) board failed open circuit
- Failure description:
  - Failure traced to a break in wire
  - Wire is 1mil (~ AWG52), which does not meet MIL-STD-981 requirements
  - There is a separation between the mold compound and the surrounding tape near the break in the wire. It is suspected that the wire traversed the void/separation in the mold compound, and mechanical stress during temperature changes broke the wire at the transition from molding compound to the void
- Disposition:
  - Do not use this lot for flight
  - For flight, project procured a lot of same construction parts with screening that included temperature cycling

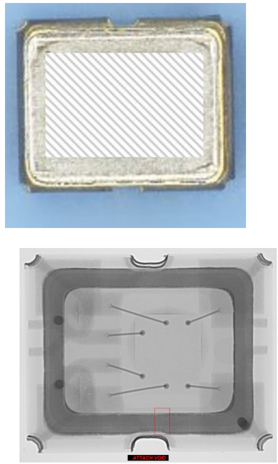
# Summary of GSFC DPA and FA

- DPA based on MIL-STD-1580 is a key element of GSFC Parts Selection/Screening Protocols per EEE-INST-002
  - Overall rate of non-conformances found during DPA for the past 6 years has been 42%
  - GSFC employs a DPA Failure Review Board to review/disposition lots that do not pass DPA
    - Options include reject lot, use as-is or screen/reprocess for the observed condition to provide assurance for the intended application
    - 4% of all lots are rejected for flight use
- FA in support of NASA programs
  - Microcircuits and Capacitors make up 50% of all FAs
  - EOS and Manufacturing defects account for 59% of FA findings

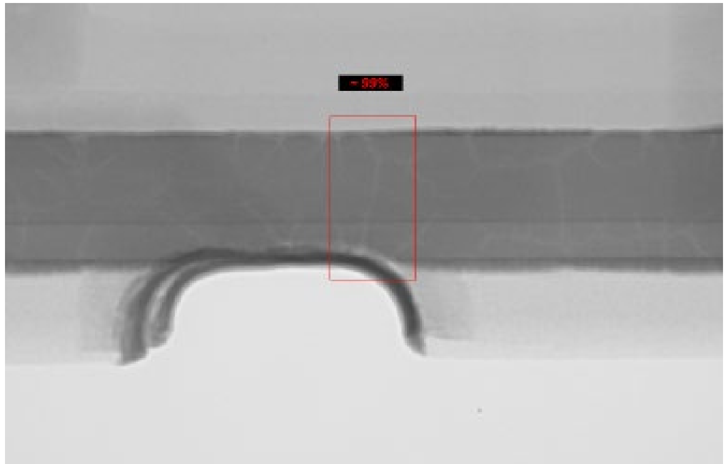
# Examining Hermeticity of UB Packages with Lid Seal Voids

# Lid Seal Void Criteria and GSFC Experience

- MIL-STD-883 TM 2012 Radiography has a lid seal void criteria, rejecting packages with sealing width reduced by more than 75 percent
  - This applies to packages with solder seals, where a ring of solder is used on the perimeter of the lid to bond lid to the package
- It is not uncommon to observe parts that are hermetic per MIL-STD-883 TM 1014, but fail the lid seal void criteria, resulting in rejection of devices
  - GSFC has many examples of DPA with lid seal voids exceeding 75% criteria, but passing hermeticity and IGA
- Is there a long-term concern with packages that exhibit lid seal voids?
  - Review of NASA GSFC's failure analyses and evaluation of EEE parts showed no examples of part failures traced to loss of hermeticity due to voids in the lid seal
    - Review of data for years 2010 – 2021
    - In contrast, there were failures of EEE parts traced to loss of hermeticity for reasons other than lid seal voids



*Optical image and X-Ray of the device (part markings removed)*



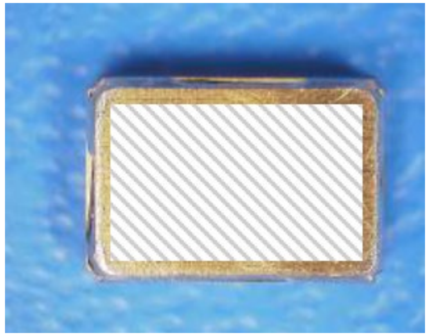
*Close-up X-Rays of the package showing void in solder lid seal*

| SAMPLE ID | | 3 | 4 | 5 |
|---|---|---|---|---|
| Pass/Fail | | PASS | PASS | PASS |
| Inlet Pressure | torr | N/A | N/A | N/A |
| Sys. Pressure | torr | 4.1e-6 | 3.9e-6 | 4.2e-6 |
| Sample Temp. | °C | 99.4 | 99.3 | 99.6 |
| Relative Humidity | RH% | 0.1 | 0.1 | 0.2 |
| Volume | cc·atm | 0.001 | 0.001 | 0.001 |
| Nitrogen | ppmv | 995,947 | 996,059 | 995,435 |
| Oxygen | ppmv | ND P | ND P | ND P |
| Argon | ppmv | 44 | 59 | 59 |
| Carbon Dioxide | ppmv | 2,834 | 3,179 | 2,689 |
| Moisture | ppmv | 962 P | 618 P | 1,652 P |
| Hydrogen | ppmv | 187 | 85 | 165 |
| Methane | ppmv | ND | ND | ND |
| Ammonia | ppmv | ND | ND | ND |
| Helium | ppmv | ND | ND | ND |
| Fluorocarbon | ppmv | ND P | ND P | ND P |
| UNKNOWN | ppmv | 26 | ND | ND |

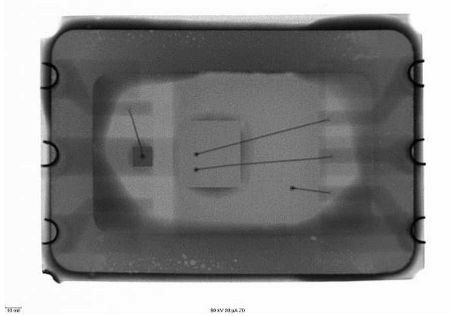
*IGA results of three packages with lid seals showing voids >99%*
*IGA results show a hermetically sealed device*

# Examining Hermeticity Stability of Parts with Lid Seal Voids

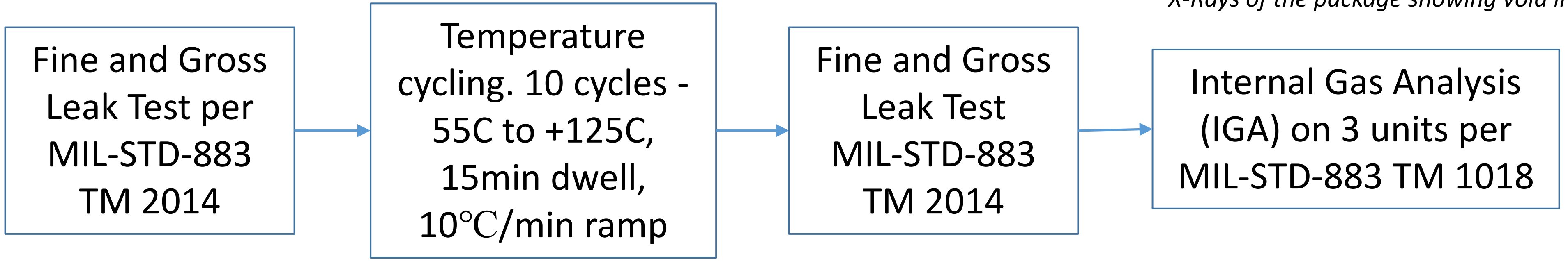
- Background of parts
  - A commercial device screened to MIL-STD-883
  - Package style: UBA
  - Hermeticity test at manufacturer results: fine leak (147 passed/1 failed) and gross leak (147 passed/0 failures) passed.
  - X-Ray of 30 received units showed all units with lid seal voids in excess of 75%, with many units showing lid seal voids spanning 95% of the seal
- Test Plan
  - 30 units with lid seal voids in excess of 75%, and 5 control units with lid seal passing MIL-STD-883 TM2012 criteria



*Optical image of the device (part markings removed)*



*X-Rays of the package showing void in solder lid seal*



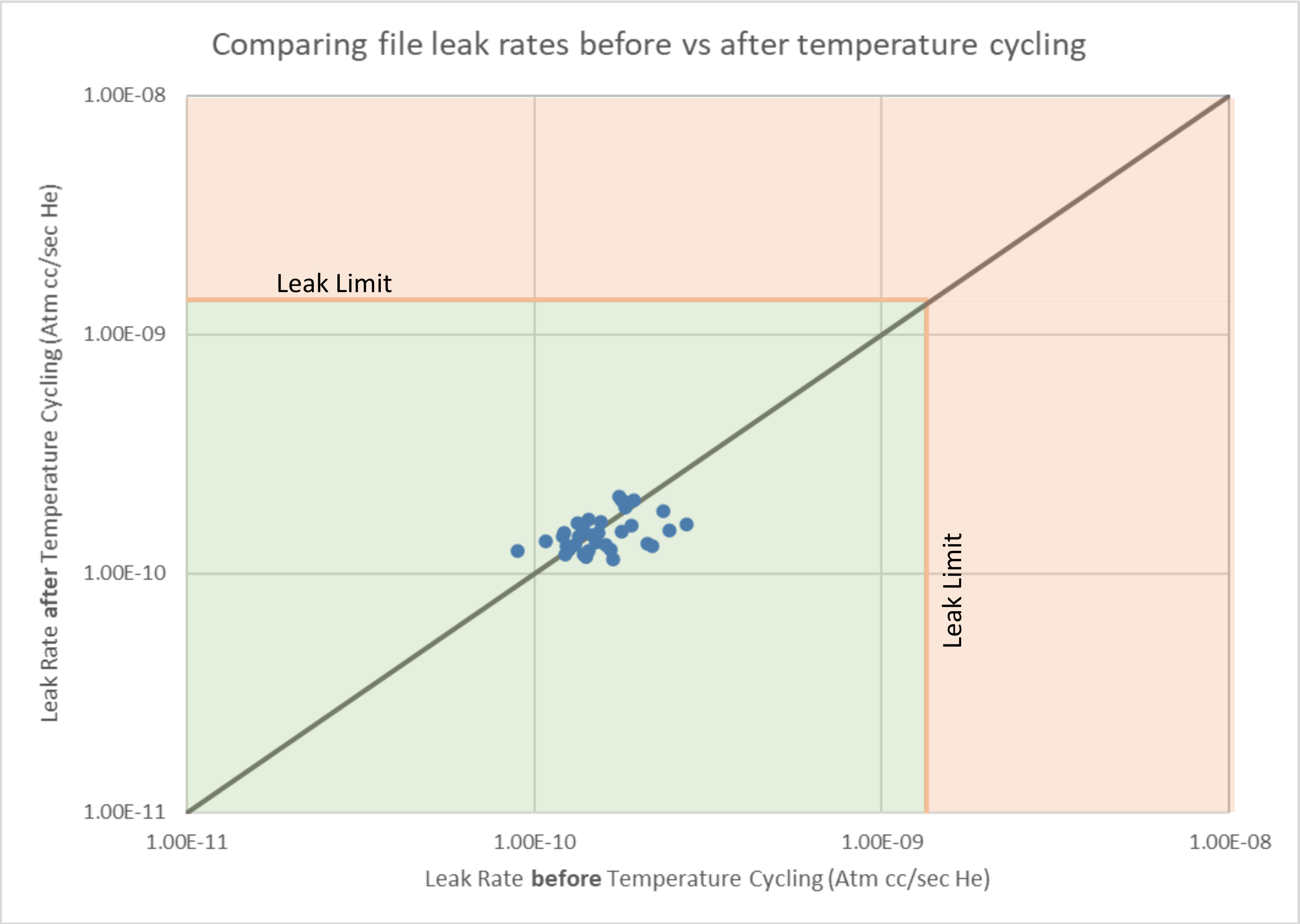
Fine and Gross Leak Test per MIL-STD-883 TM 2014

Temperature cycling. 10 cycles - 55C to +125C, 15min dwell, 10℃/min ramp

Fine and Gross Leak Test MIL-STD-883 TM 2014

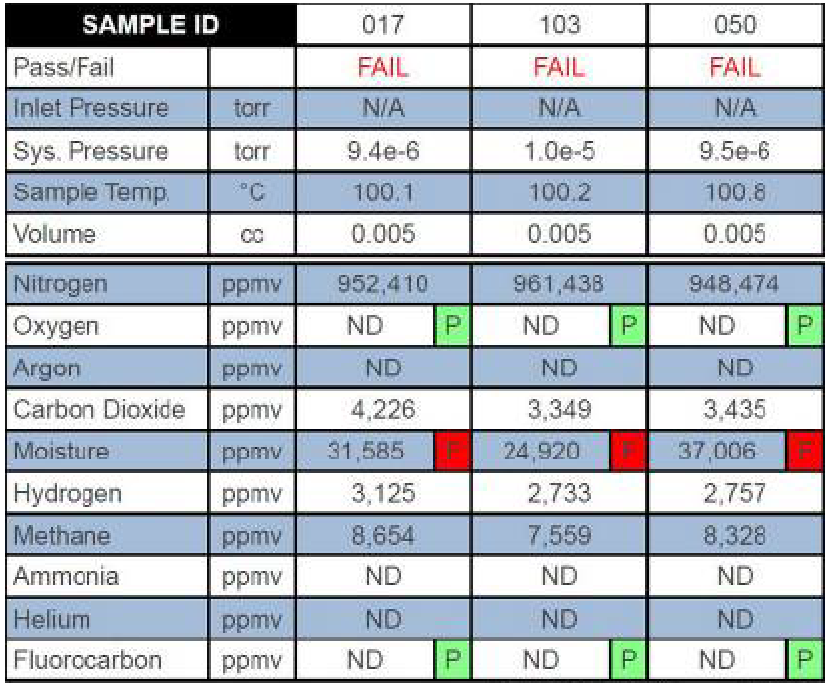
Internal Gas Analysis (IGA) on 3 units per MIL-STD-883 TM 1018

# Hermeticity Testing Before and After Temperature Cycling



- 35 units tested for fine and gross leak before and after temperature cycling
    - 30 units with lid seal voids >75%
    - 5 units with lid seal voids <75%, as controls
- All units passed fine and gross leak before and after temperature cycling
- Fine leak measurements show consistency before and after temperature cycling
- Notes on graph:
    - Red area on the graph for leak rates failing fine leak limit
    - Green area on the graph for leak rates passing fine leak limit
    - Grey diagonal line – readings on the line mean there was no change before and after temperature cycling

# IGA Results After Temperature Cycling



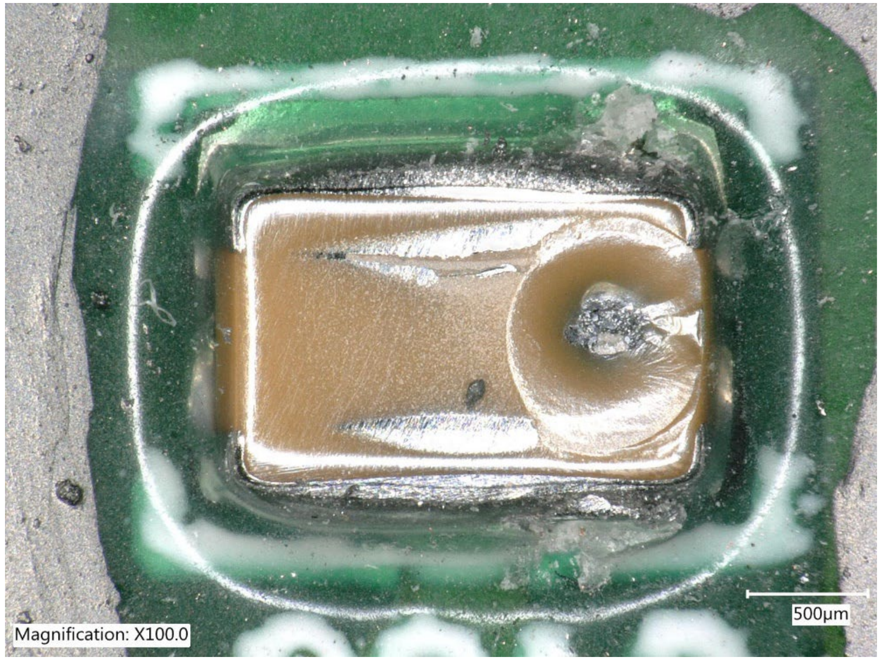
| SAMPLE ID | | 017 | | 103 | | 050 | |
|---|---|---|---|---|---|---|---|
| Pass/Fail | | FAIL | | FAIL | | FAIL | |
| Inlet Pressure | torr | N/A | | N/A | | N/A | |
| Sys. Pressure | torr | 9.4e-6 | | 1.0e-5 | | 9.5e-6 | |
| Sample Temp. | °C | 100.1 | | 100.2 | | 100.8 | |
| Volume | cc | 0.005 | | 0.005 | | 0.005 | |
| Nitrogen | ppmv | 952,410 | | 961,438 | | 948,474 | |
| Oxygen | ppmv | ND | P | ND | P | ND | P |
| Argon | ppmv | ND | | ND | | ND | |
| Carbon Dioxide | ppmv | 4,226 | | 3,349 | | 3,435 | |
| Moisture | ppmv | 31,585 | F | 24,920 | F | 37,006 | F |
| Hydrogen | ppmv | 3,125 | | 2,733 | | 2,757 | |
| Methane | ppmv | 8,654 | | 7,559 | | 8,328 | |
| Ammonia | ppmv | ND | | ND | | ND | |
| Helium | ppmv | ND | | ND | | ND | |
| Fluorocarbon | ppmv | ND | P | ND | P | ND | P |

- Three (3) units submitted for Internal Gas Analysis (IGA) after temperature cycling. All three units are X-ray rejects per MIL-STD-883 TM2012with lead seal voids in excess of 95%
- All units show no signs of air ingress: oxygen and argon levels are undetectable. If air was present, expected to see 20:1 ratio of oxygen:argon
  - Note: ND stands for non-detectable
- All units show no signs of helium ingress from helium fine leak test
- Moisture readings in excess of 5,000ppmv limit. However, the parts are known to be sealed with moisture-outgassing materials on the inside – an optical light pipe

# Summary of Lid Seal Voiding Study

- Lid seal voids in excess of 75% per MIL-STD-883 TM 2012 3.10.2.2.e criteria are not uncommon
- Review of failure analyses and evaluations at NASA GSFC between 2010-2021 shows no examples of part failures due to loss of hermeticity traced to lid seal voids
- Temperature cycling of devices with lid seal voids in excess of 95% showed no effect on hermeticity, and subsequent IGA testing showed parts retained hermetic seal
  - Test conditions: 10 temperature cycles, -55°C to +125°C, 15min dwell, 10°C/min ramp
- Hermeticity testing is recommended to judge acceptability of parts with lid seal voids

# Questions?



Multilayer ceramic chip capacitor with a cone-shaped piece of top plate separated after internal electrical short