NASA Parts “Graveyard”
Examples of NASA EEE Parts Failure Experiences

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Unclassified

Outline

- **Acronym List**
- **Gotcha Experiences**

Acronym List

Acronym	Definition	Acronym	Definition
3D-CT	Three Dimensional-Computed Tomography	HEXFET	A type of Power MOSFET
ATVC	Ascent Thrust Vector Control	ICESat	Ice, Clouds, and Land Elevation Satellite
Au	Gold	In	Indium
BeCu	Beryllium Copper (alloy)	JFET	Junction gate Field-Effect Transistor
CCA	Circuit Card Assembly	JWST	James Webb Space Telescope
CERES	Clouds and the Earth's Radiant Energy System	LDC	Lot Date Code
Crit	Criticality	MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
CSI	Customer Source Inspection	NAND	NOT AND
DPA	Destructive Physical Analysis	NASA	National Aeronautics and Space Administration
ECO	Engine Cut-Off	NEPP	NASA Electronic Parts and Packaging (Program)
EEE	Electrical, Electronic and Electromechanical	PA	Parts Analysis
ESD	Electrostatic Discharge	PC	Printed Circuit
EPI	Epitaxial	SEM	Scanning Electron Microscope
FIB	Focused Ion Beam	S/N	Serial Number
FPGA	Field Programmable Gate Array	STEREO	Solar TErrestrial RElations Observatory
GLAS	Geoscience Laser Altimeter System	SWIFT-BAT	Burst Alert Telescope on the Swift satellite
GSFC	Goddard Space Flight Center	TiW	Titanium Tungsten
HBM	Human Body Model		

“Learn from the mistakes of others. You can’t live long enough to make them all yourself.”

Eleanor Roosevelt

"Only a fool learns from his own mistakes. The wise man learns from the mistakes of others."

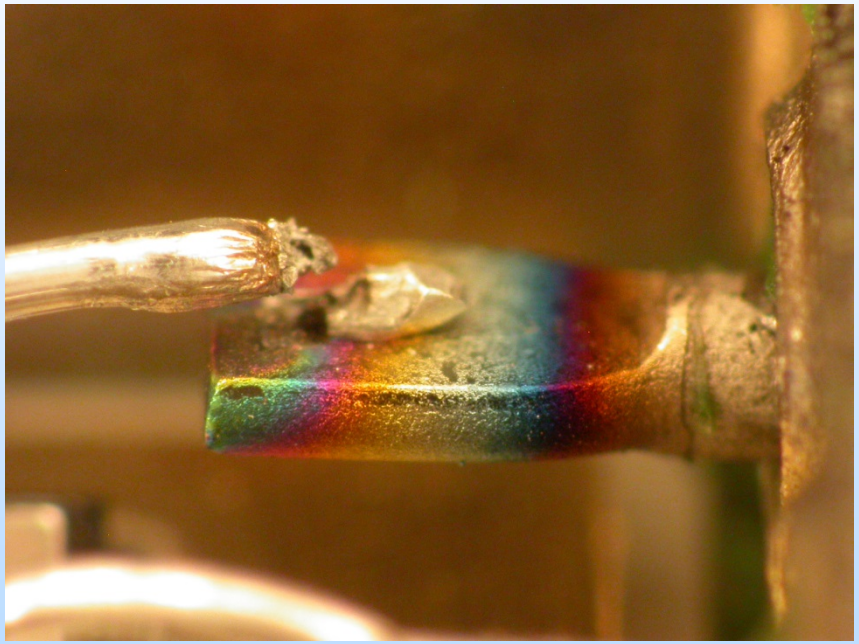
Otto von Bismarck

“Somewhere Over the Rainbow”

Part Type: Power Rectifier

Description: External mechanical stress catastrophically damaged glass seal

- **Allowed movement of lead and cracking at the heel of the wire bond at the lead paddle inside the device**
- **As the crack grew, conductive path decreased in cross-section increasing electrical resistance and corresponding joule heating.**
- **The aluminum wire became liquid in the vicinity of the crack along the length of wire leading to the die**
- **Residual bending stress caused the wire to spring up, disconnecting the wire**
- **The final assault was arcing and vaporization of the remnant of aluminum filament connecting the lead and wire.**



Courtesy of Jay Brusse and Chris Greenwell, ASRC Federal at NASA/GSFC Code 562

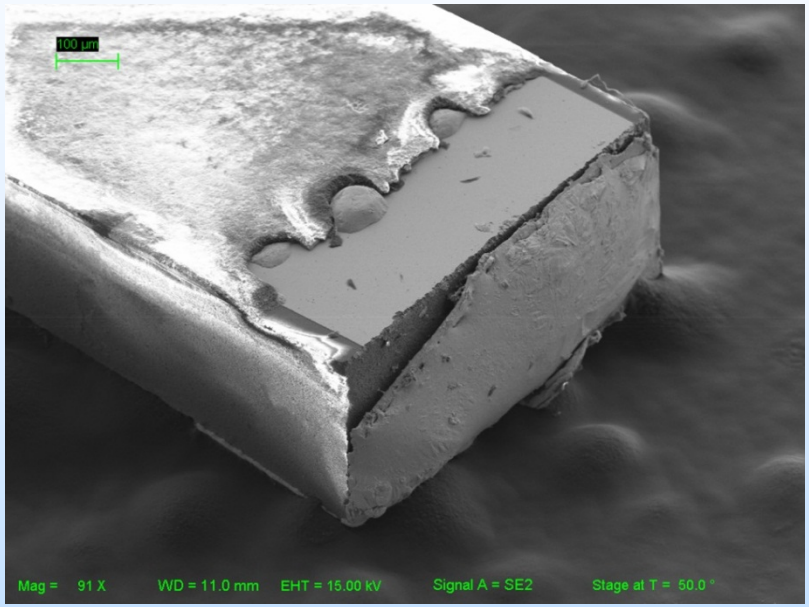
<u>Ultimate cause of failure</u>:

A design that did not anticipate the tremendous mechanical stress that could be imposed on the delicate glass feed-through seals of this device.

“Is this A-Peeling to You?”

Part Type: 100 ohm Thin Film Chip Resistor

- **Description:**
  As-received in the Parts Analysis (PA) Lab one end termination metallization was missing down to the Titanium Tungsten (TiW) layer
- **The end face metal was peeling from the alumina substrate.**
- **Part measured 5.7 kΩ between the end faces.**
- **Probing from the top side TiW layer to the good end revealed 100 Ω.**



Courtesy of Jay Brusse and Chris Greenwell, ASRC Federal at NASA/GSFC Code 562

<u>Suggests two failure mechanisms</u>:

1. **Defect in the nickel strike-to-nickel plate layers allowed molten solder to consume/ penetrate the nickel strike layer and dissolve the gold layer**
2. **Improper thickness or adhesion of the TiW layer on the end face allowed a void to develop that subsequently resulted in the observed failure.**

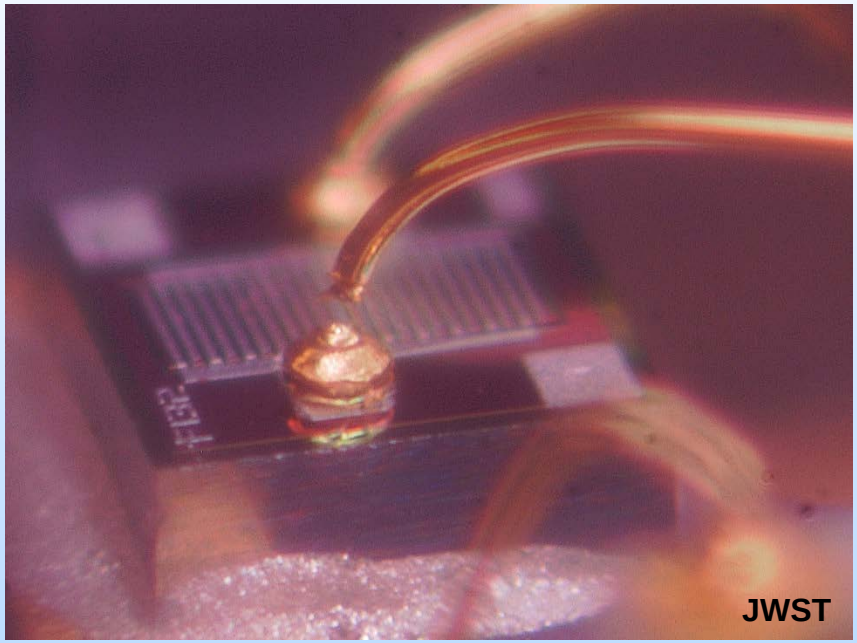
These mechanisms indicate a manufacturing defect and not an end user mishap

“The Guillotine”

Part Type: Solid-state relay

Description:

- Failure caused by manufacturing-induced mechanical damage that severed an internal bond wire.
- Broken wire was visible in X-ray prior to delidding the device.
- Difficult to see optically during internal examination
- Scratch damage on the die surface should have been seen by a pre-cap inspection
- It is questionable if this device functioned properly during manufacturer testing.



Broken wire connects to a JFET used to turn off the output MOSFETs

With the JFET removed from the circuit, MOSFETs were slow to turn off since charge on the gate (capacitance) had to be discharged through the phototransistors.

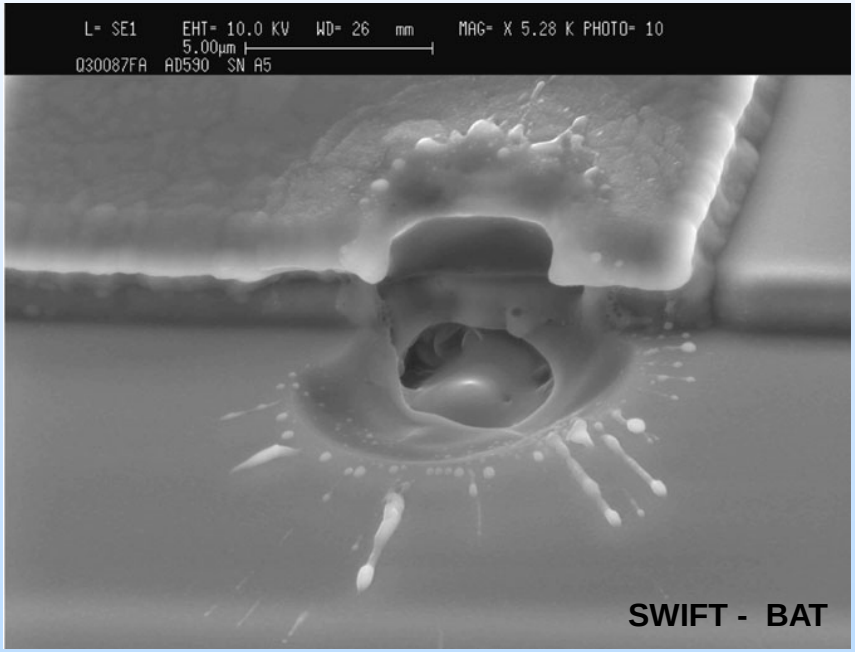
“Lightning Never Strikes Twice?”

Part Type: Temperature Transducer

Description:

Suspect parts associated with calibration errors

- All 3 devices had a single, visible, damage site associated with the die metallization
- Damage appeared to be between the metal and a substrate diffusion or epi-layer.
- Substrate is connected to a transistor gate
- Hidden damage found in metal layer A5
- Spares subjected to Human Body Model (HBM) Electrostatic Discharge (ESD) pulses showed similar damage
- 3/4 parts, had similar damage but did not show electrical degradation (latent damage?)
- Simulation did not produce devices with both physically similar damage and calibration errors



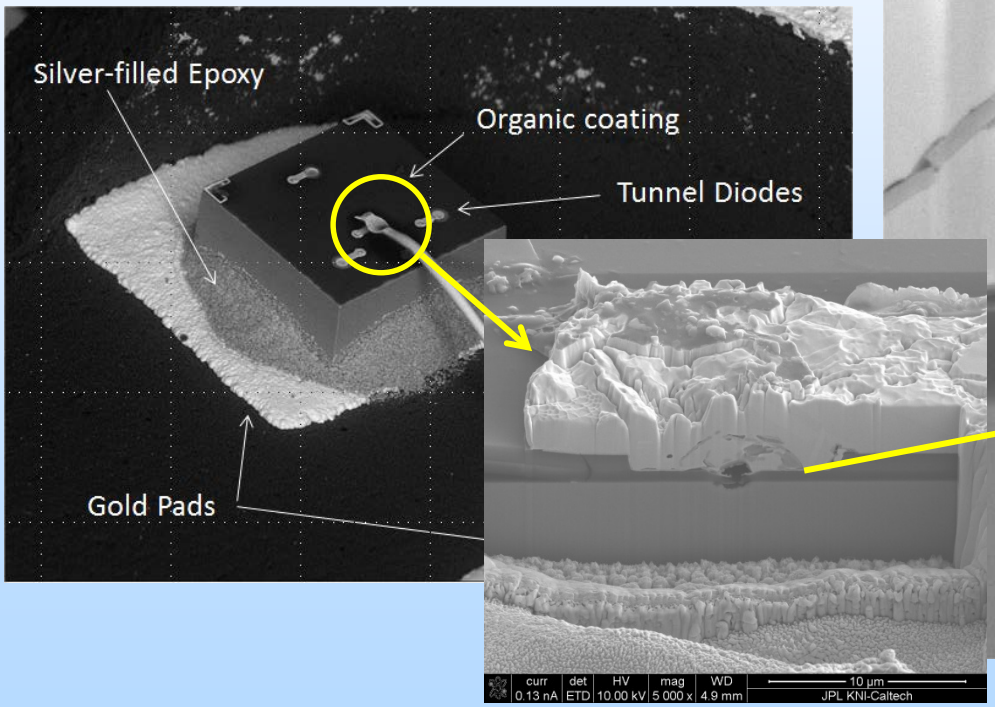
Suspected Cause:

It is suspected an ESD pulse >15kV can produce both effects, including hidden damage. It appears reasonable that ESD damaged the flight parts

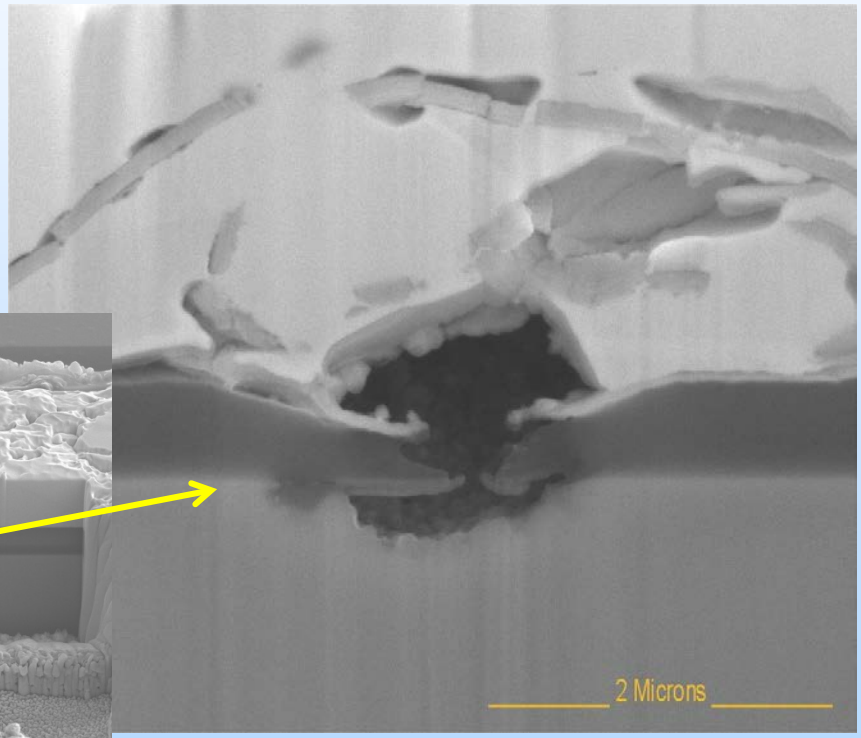
“It Sure Can”

Tunnel Diode Failure by Electrostatic Discharge

Tunnel diode SEM backscatter image overview



Damages Tunnel Junction Region by ESD at -600 V



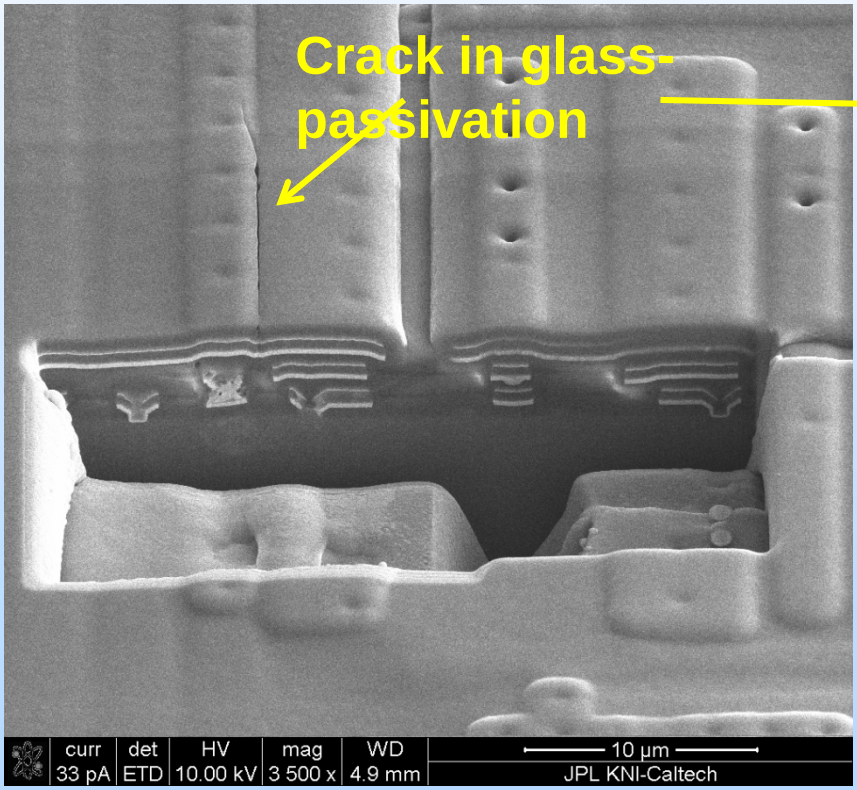
To be presented at NEPP ETW June 17-19, 2014 and published on nepp.nasa.gov.

“And Again”

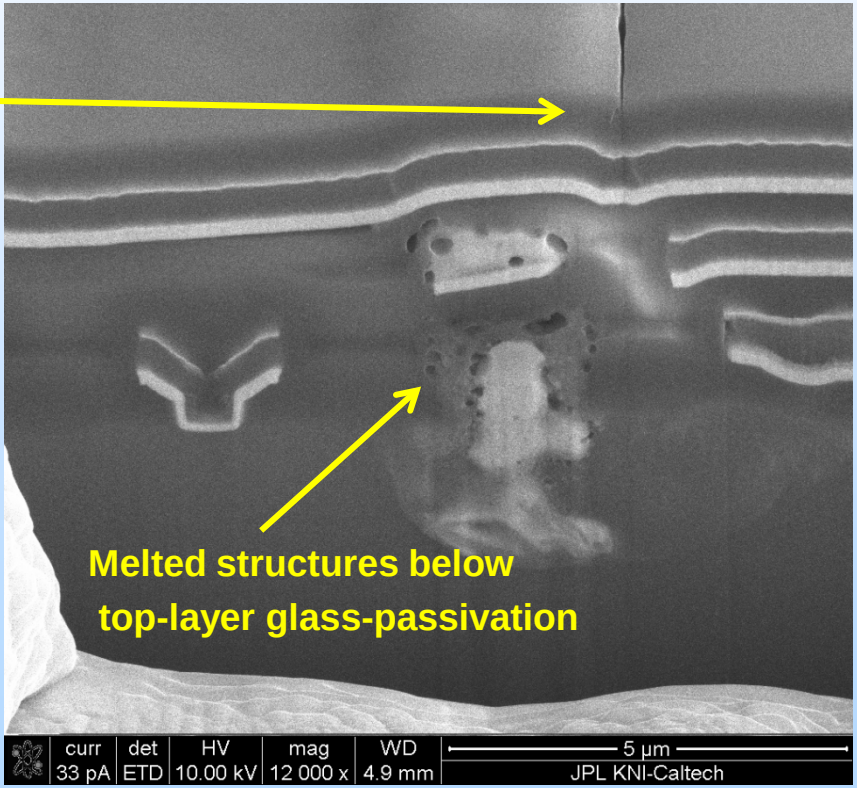
Crack in Top Layer Semiconductor Glassivation Reveals Subsurface Anomaly

- **Part Failed Burn-in**
- **Optical showed anomaly that SEM revealed as a crack**
- **A FIB is an invaluable “toy” to have**

SEM/FIB Image of Subsurface Anomaly



Close-up View of Anomaly



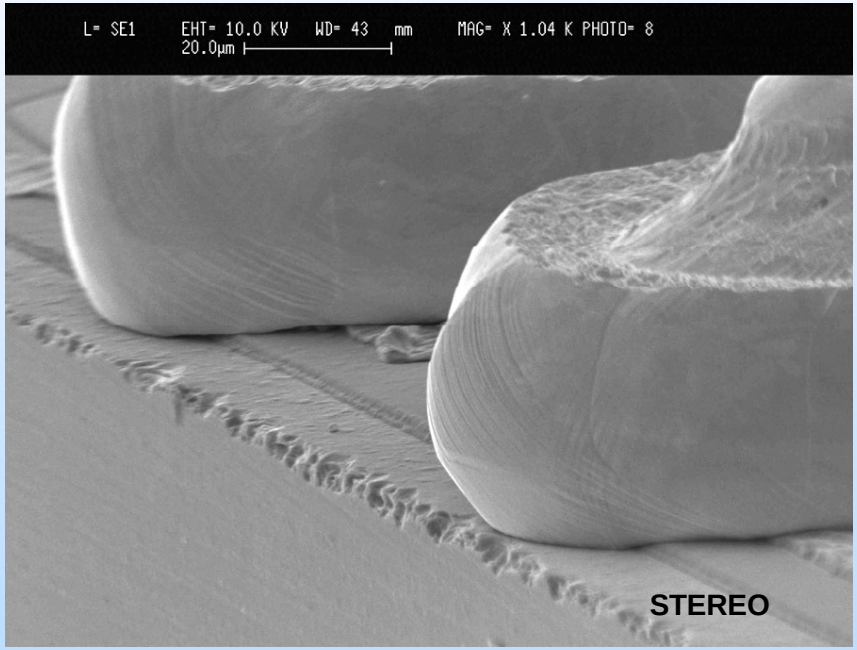
To be presented at NEPP ETW June 17-19, 2014 and published on nepp.nasa.gov.

“My Feet Hurt”

Part Type: **Charge Sensitive Pre-Amp & Discriminator Hybrid**

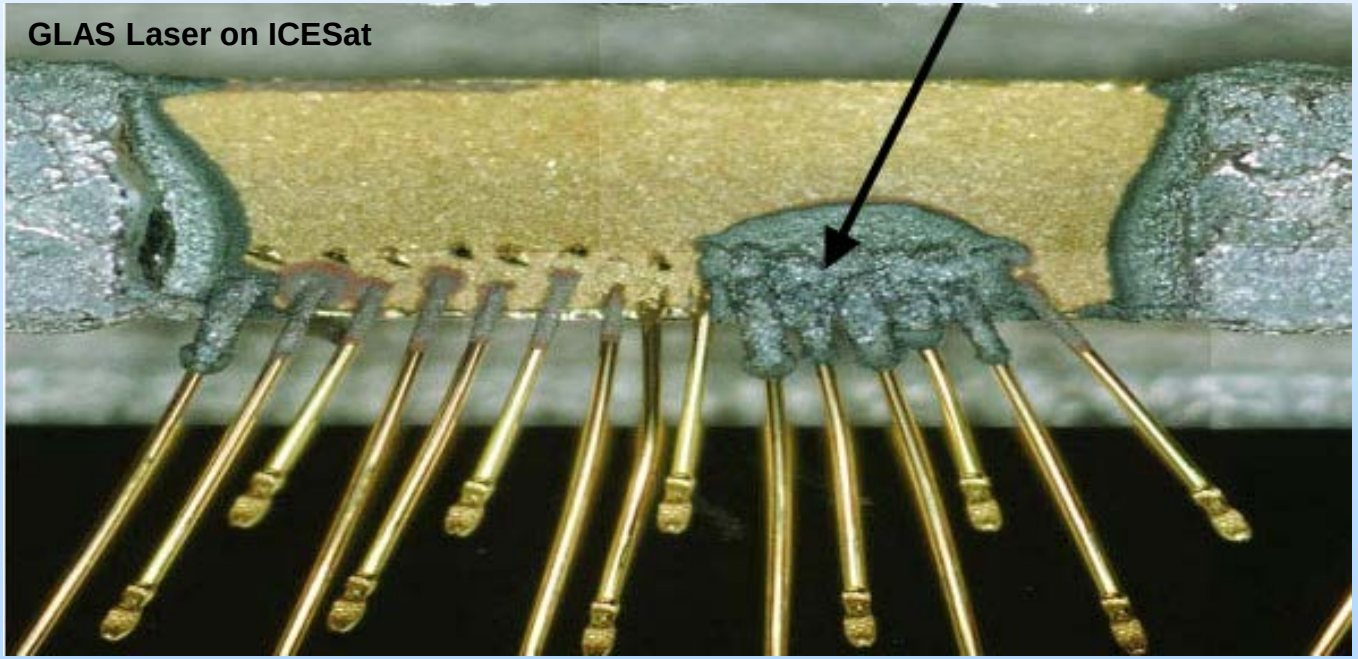
Description:

- Cause of failure was a workmanship error
- Relatively large diameter ball bonds shorted to the unpassivated die edge of the transistor that drives the output stage of the hybrid.
- Thorough quality control inspection at the manufacturer should have revealed this workmanship defect
- A pre-cap customer source inspection (CSI) also could be expected to reveal such a defect
- Secondary finding of unacceptable metallization on the transistor is also of serious concern
- Optical inspections would not reveal this defect, but a destructive physical analysis (DPA) and Scanning Electron Microscope (SEM) inspection is expected to find this type defect.



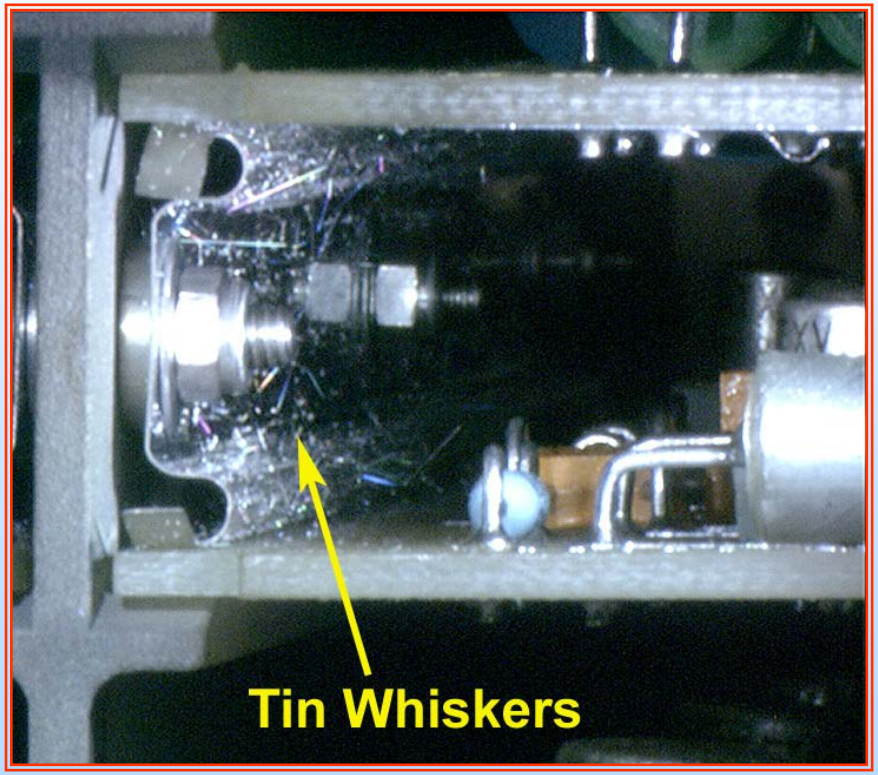
“Attack of the Killer Intermetallic”

- **Gold (Au) leads and indium (In) solder were never meant to interconnect**
  - **Au leads were wire bonded between laser bar and the alumina spacer bar**
  - **In solder was used as an attach between different laser bars**
- **After on-orbit failure, investigation of available laser diode arrays found significant amounts of In-Au intermetallic material all around and on the gold wire bonds**
  - **During reflow, In solder wicked on and around Au wires**
  - **Molten In would react fast with the Au, although slower diffusion reaction would continue in solid state as well**



“Shuttle Stubble”

Tin Whiskers Discovered in Space Shuttle Avionics



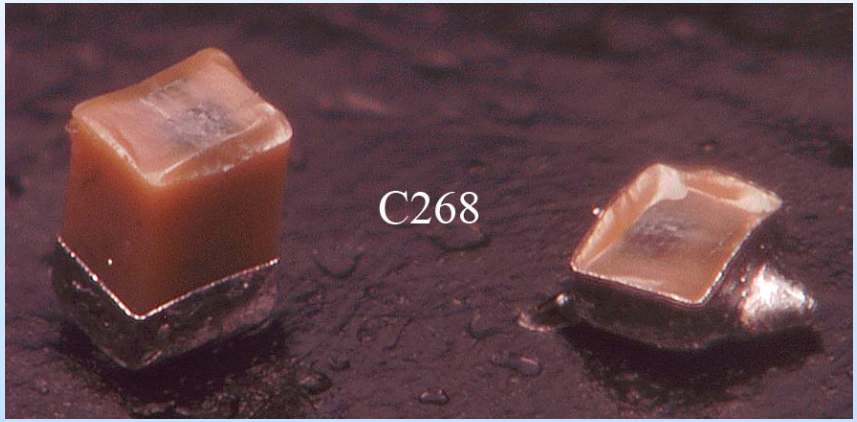
- **Card Guides were PURE TIN-PLATED beryllium copper (BeCu)**
- **~1/3 of the installed card guides had massive tin whisker infestation**
  - **~10,000 whiskers per card guide**
  - **Many whiskers > several millimeters in length**
  - **Whiskers up 24-mm (~1 inch) long were documented**
- **Some detached whiskers were found resting on the failed PC card including one whisker in a position suggesting it had shorted a component terminal to ground causing the observed failure in ATVC S/N 34**

“The Front Fell Off”

Part Type: Ceramic Chip Capacitor

Description:

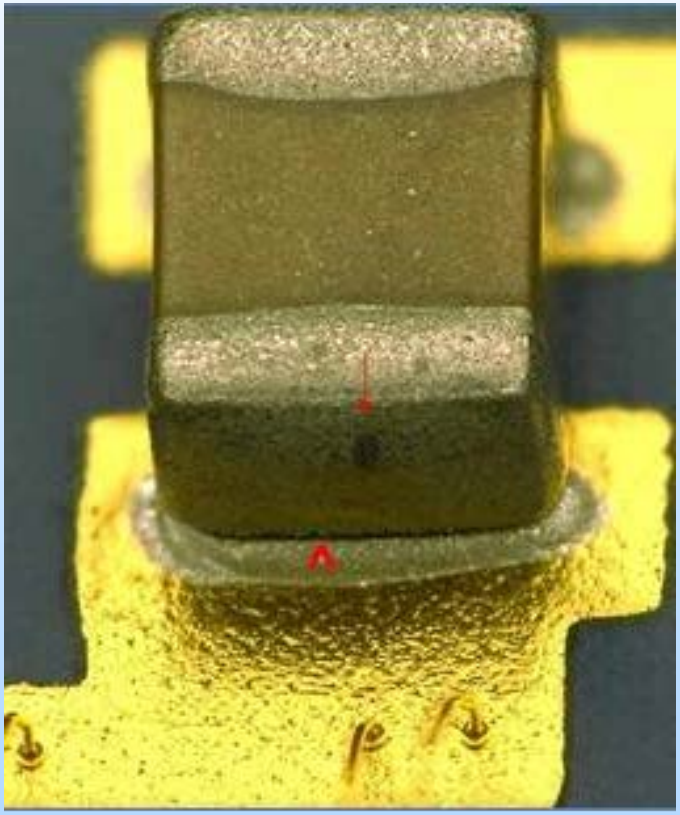
- **Capacitor appears to have cracked during initial installation on the Circuit Card Assembly (CCA)**
- **Initial installation includes the original solder reflow and the probable hand solder touch-up**
- **The touch-up process may have produced stresses (especially tensile stress) on the capacitor causing cracking beneath one end termination**
- **Other factors that may have contributed include forces by tools used to solder the components to the CCAs.**



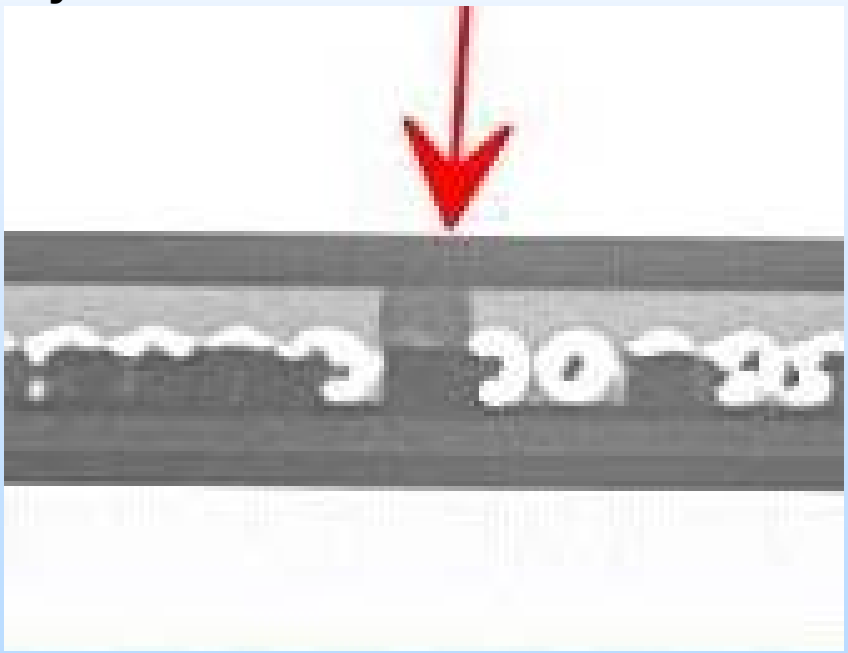
Courtesy of Jay Brusse and Chris Greenwell
ASRC Federal at NASA/GSFC Code 562

“Smile, You’re on NASA Camera”

Silver Epoxy Bond is Cracked on Multiple Products from a Specific Range of LDCs



X-ray Showing a Debonded Capacitor Stuck to the Getter Material on the Hybrid Lid



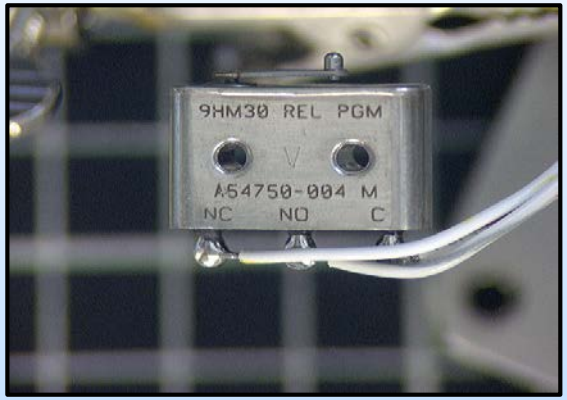
“Moon Landing?”

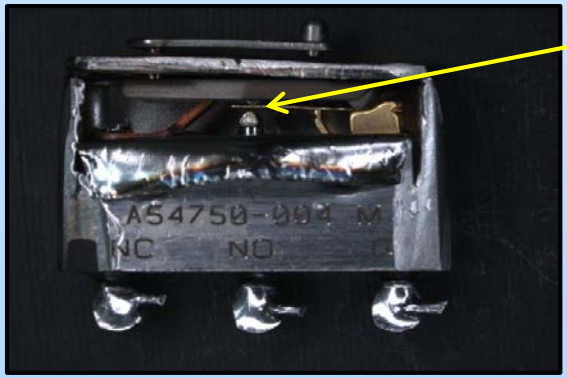
Micro switch - Reusable Solid Rocket Booster

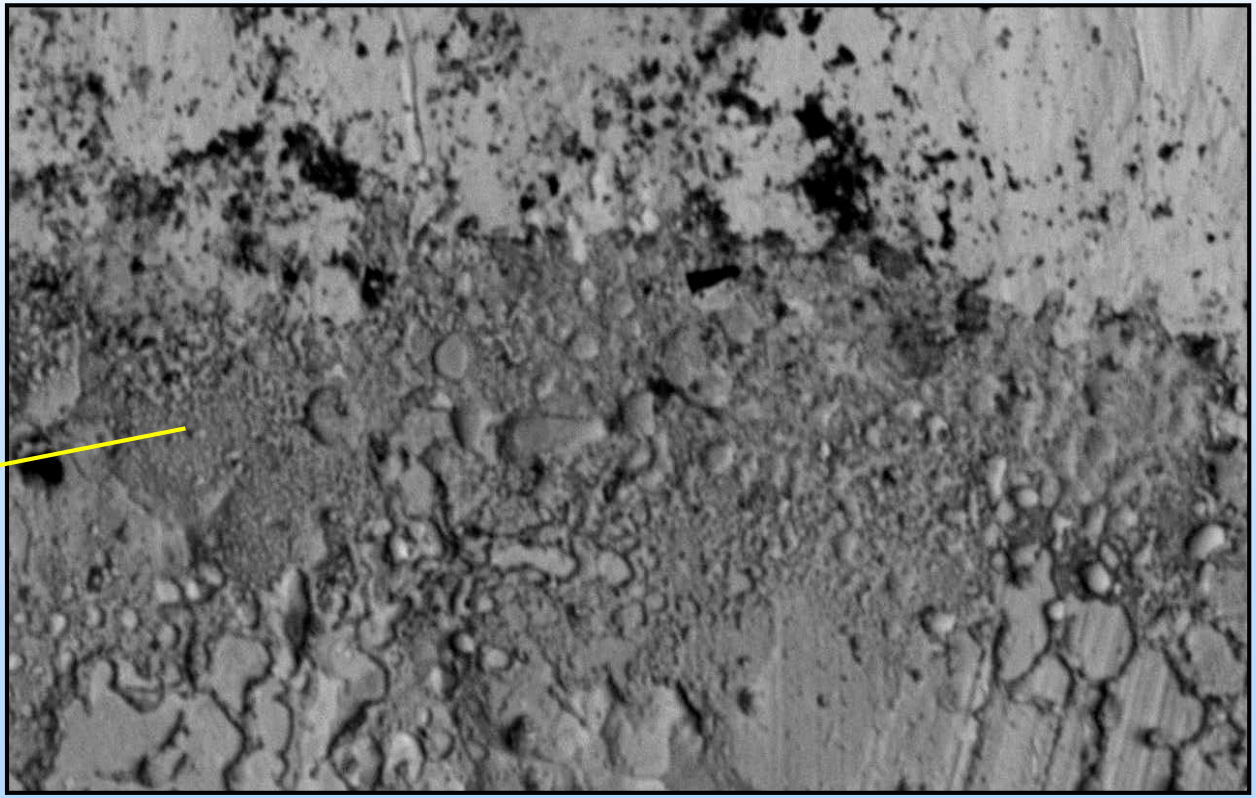
MSFC-STD-3012 Grade 2 EEE Part

- Micro switch failed during flight and later verified by electrical testing
- Failure due to contamination between switch contacts created at manufacture (arrow)
- Material was “gettered” by electric fields generated during cycling
- Unfortunately, the switch was cycled at currents too low to clean contacts

Actually , currents used were well below manufacturer's recommendation





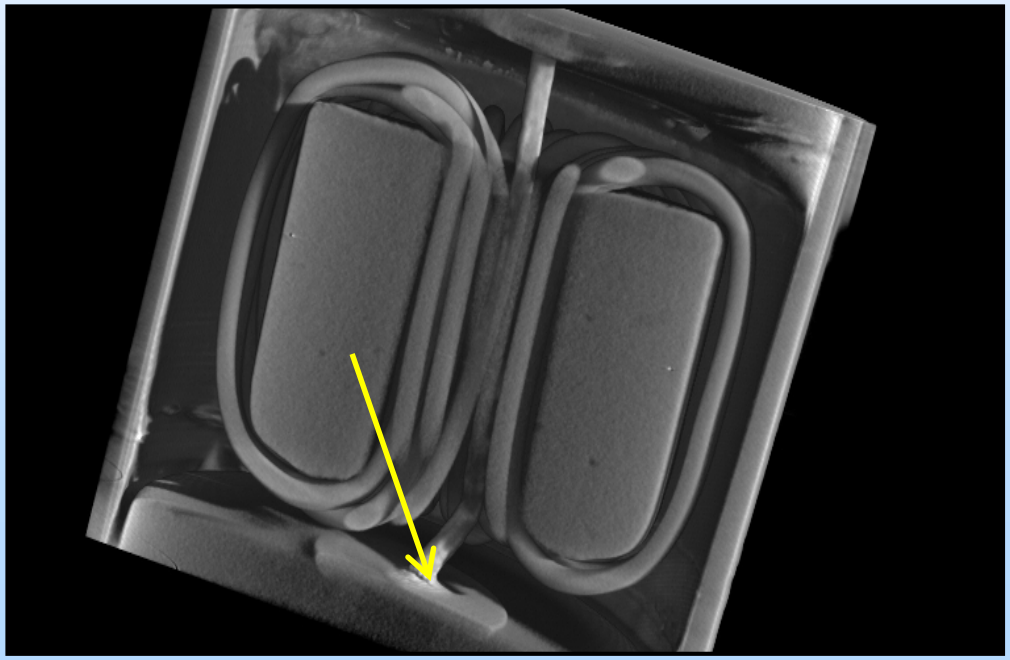


“Oh My, What Big Eyes You Have”

EMI Filter – Reusable Solid Rocket Booster”

MSFC-STD-3012 Grade 2 EEE Part

- Failure during vibration due to manufacturer issue
- “Squeezing” of capacitor to inductor (in view) to fit in part cavity caused excessive bend in inductor wire resulting in a stress riser
- Fracture found non-destructively using three dimensional computed tomography (3D-CT)
- Filter is used in a Crit 2 circuit.

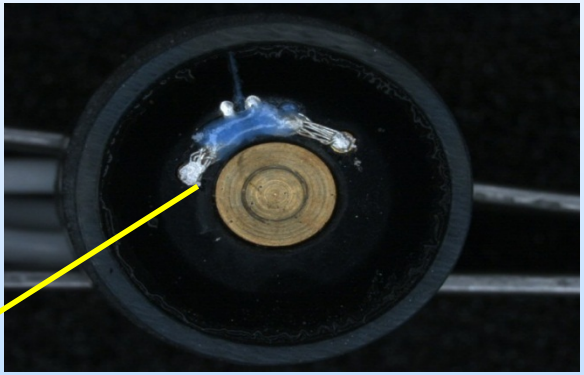


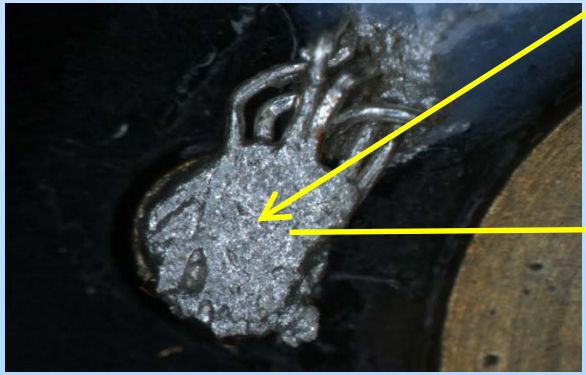
“Just a Tick”

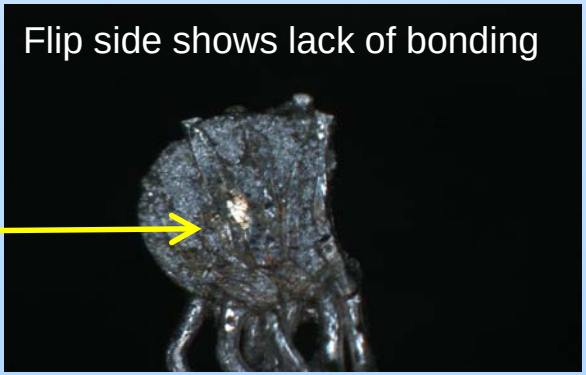
Potentiometer – Environmental Control Life Support System

MSFC-STD-3012 Grade 4 EEE Part

- Failure found during electrical testing
- Failure due to a manufacturing issue, namely, a poor weld
- Manufacturer knew the welding job was suspect and tried to provide a safety net by adding silver epoxy, which did not work
- The wire eventually lifted off its stub.



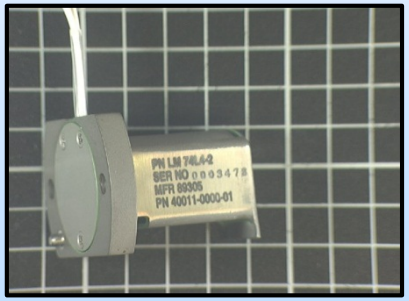


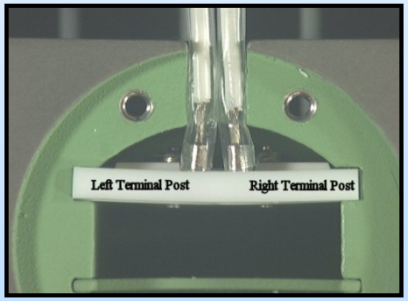


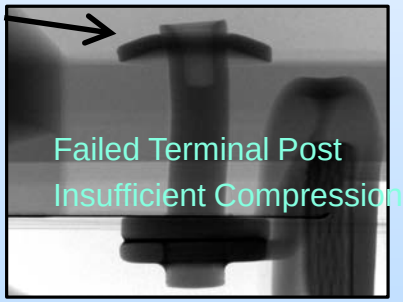
Engine Cut-Off Sensor – Shuttle External Tank

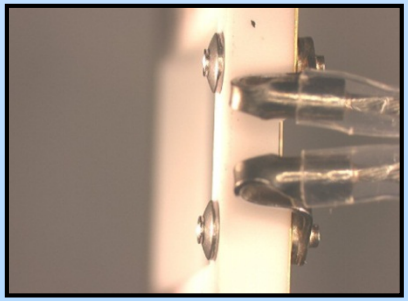
MSFC-STD-3012 Grade 1 EEE Part in Crit 1R Circuit

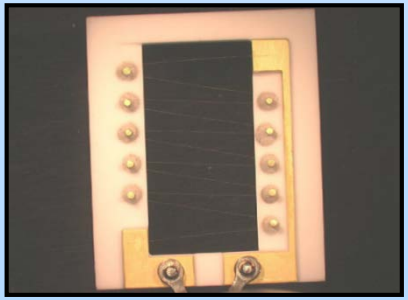
- Failure on launch pad due to intermittent electrical signal
- Root cause found to be process creep
- Belleville washer (arrows) was supposed to be compressed sufficiently to load terminal post to make contact. If the washer is compressed too much, the gold-on-ceramic breaks and the most expensive part of the sensor has to be discarded
- Technicians were “afraid” to compress the washer too much to the point the terminal post was not even loaded
- Along with silicone contamination issues found on the ECO feed through connector, several launches were scrubbed until both issues were found and finally resolved.

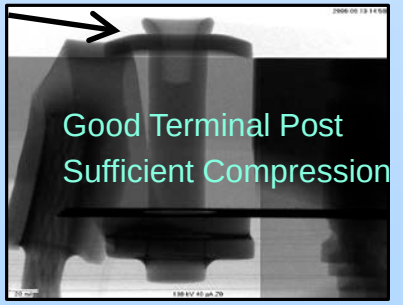










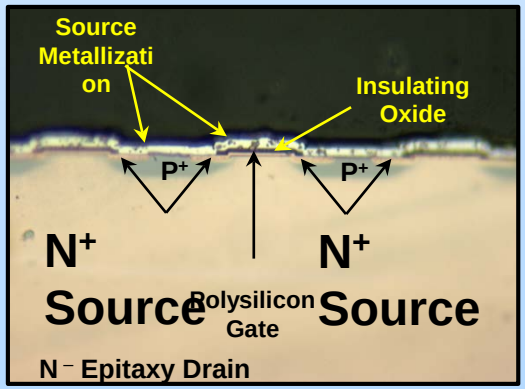


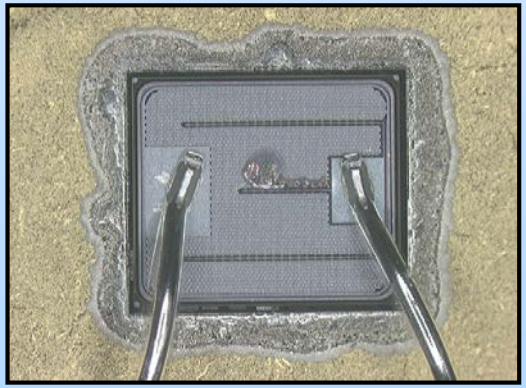
“A Source Spot”

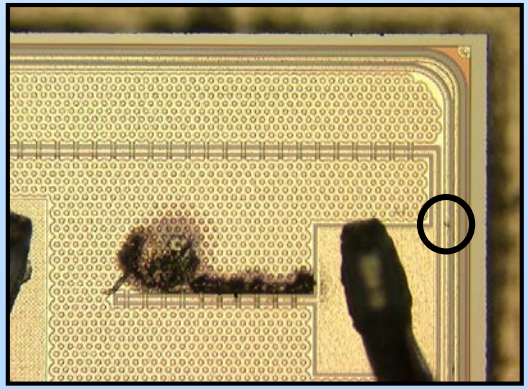
HEXFET – Materials Science Research Rack

MSFC-STD-3012 Grade 2 HEXFET

- Failure due to electrical overstress between source and drain (a reverse voltage transient)
- Verified via curve tracing
- Failure occurred at post test shipping in both a flight unit and a qualification units
- Reveals the importance of maintaining ground support equipment
- Voltage transient had to exceed several hundred volts because even the guard band (black circle) was damaged as indicated by an arcing trace.



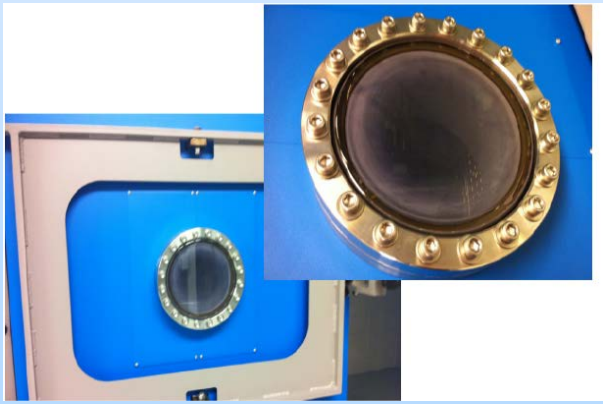




“A Bad Case of Gas”

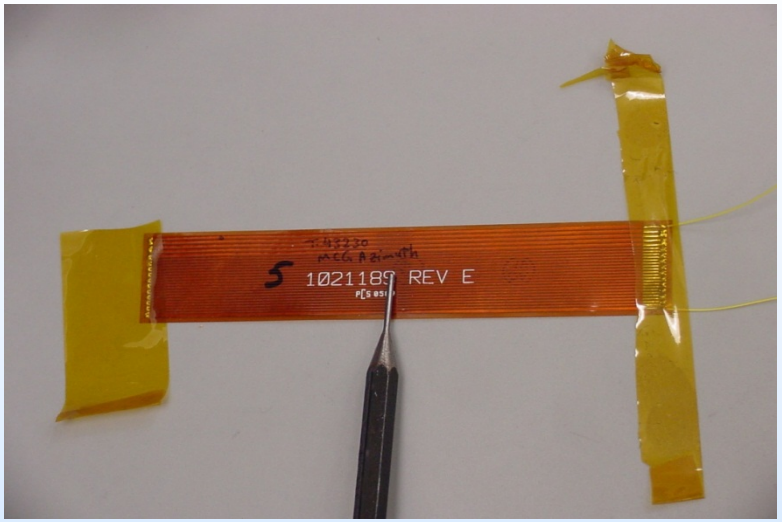
M24308/S311-P04 D-Sub Connectors

- Parts subjected to long term baking to assess outgassing
- Used ASTM E595 test but for >400 hours to assess long-term performance
- Connectors with thermoset insulators passed, thermoplastic ones failed

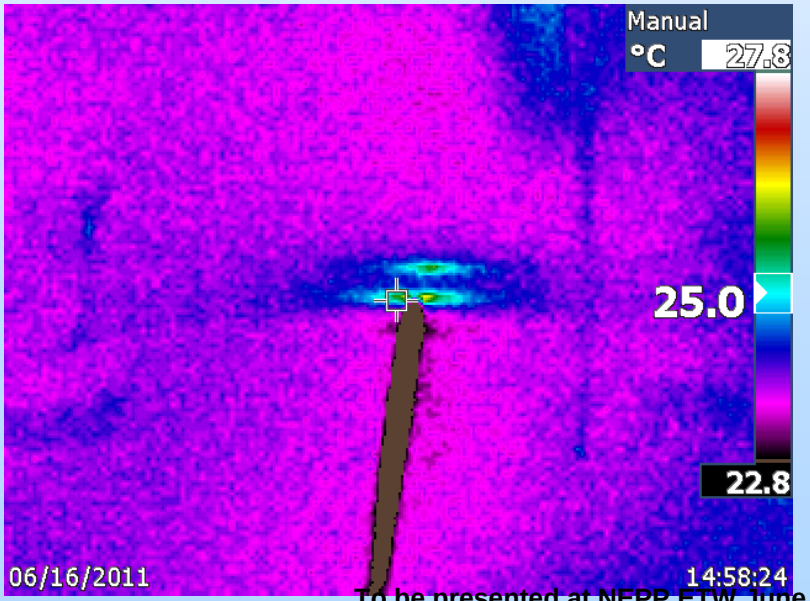


“Best to Stay Flexible”

CERES Flex Cable Qualification Issues

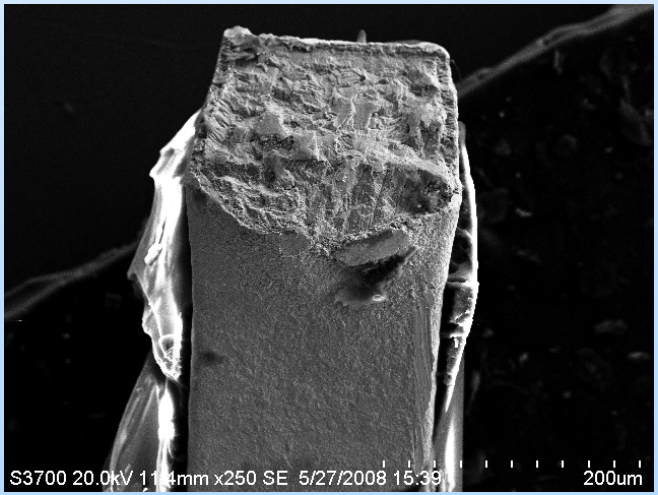


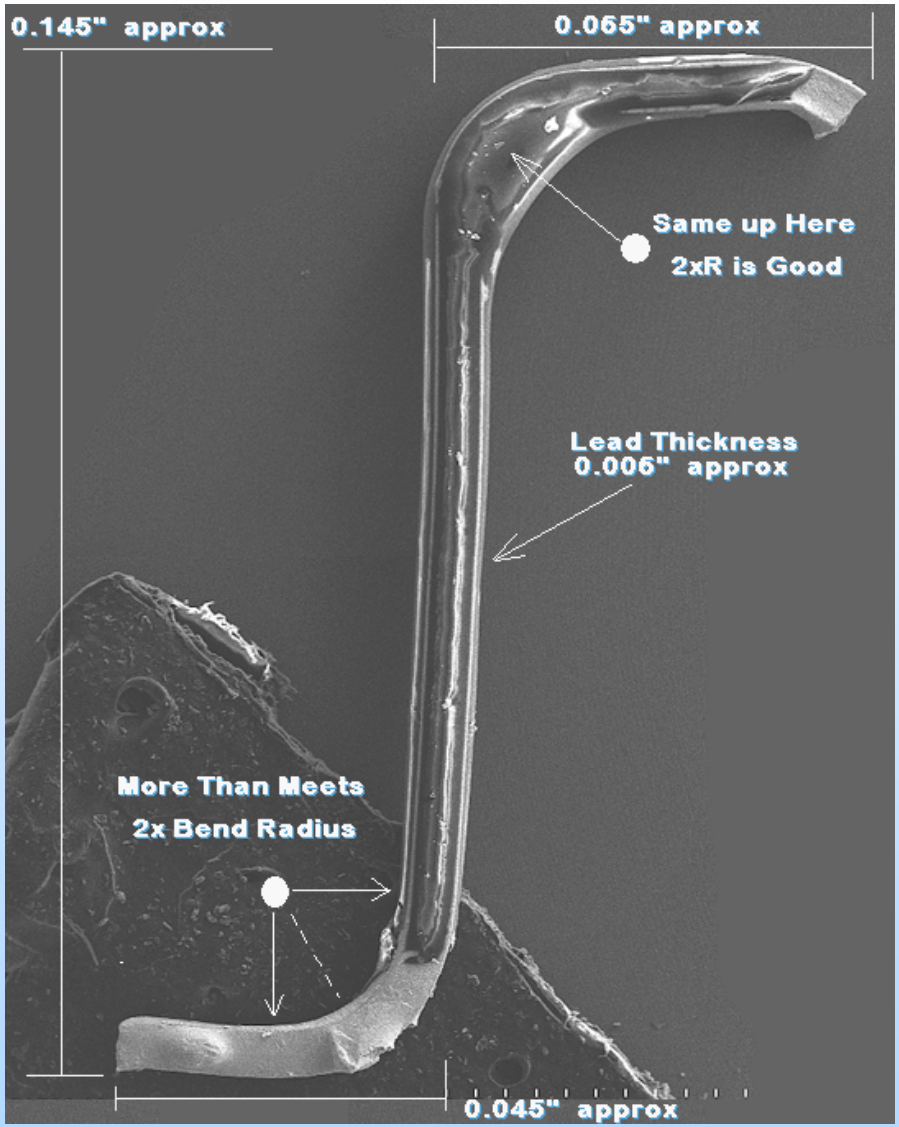
- “Brown” is the thermal image for a frozen Nine-Penny nail as a pointer to the failed “electrically heated” copper ribbon in failure mode
- Visual photo is for orientation and location
- Most copper failures were under white acrylic silkscreen text. As seen below…..
- <u>Silkscreen marking not present on the heritage parts which had exceptional performance</u>



Quad 208 FPGA pins blown out in vibe testing

- Vibration test set-up allowed resonances to create local vibe levels of over 200gs
- <u>Parts are only rated to 20gs</u>



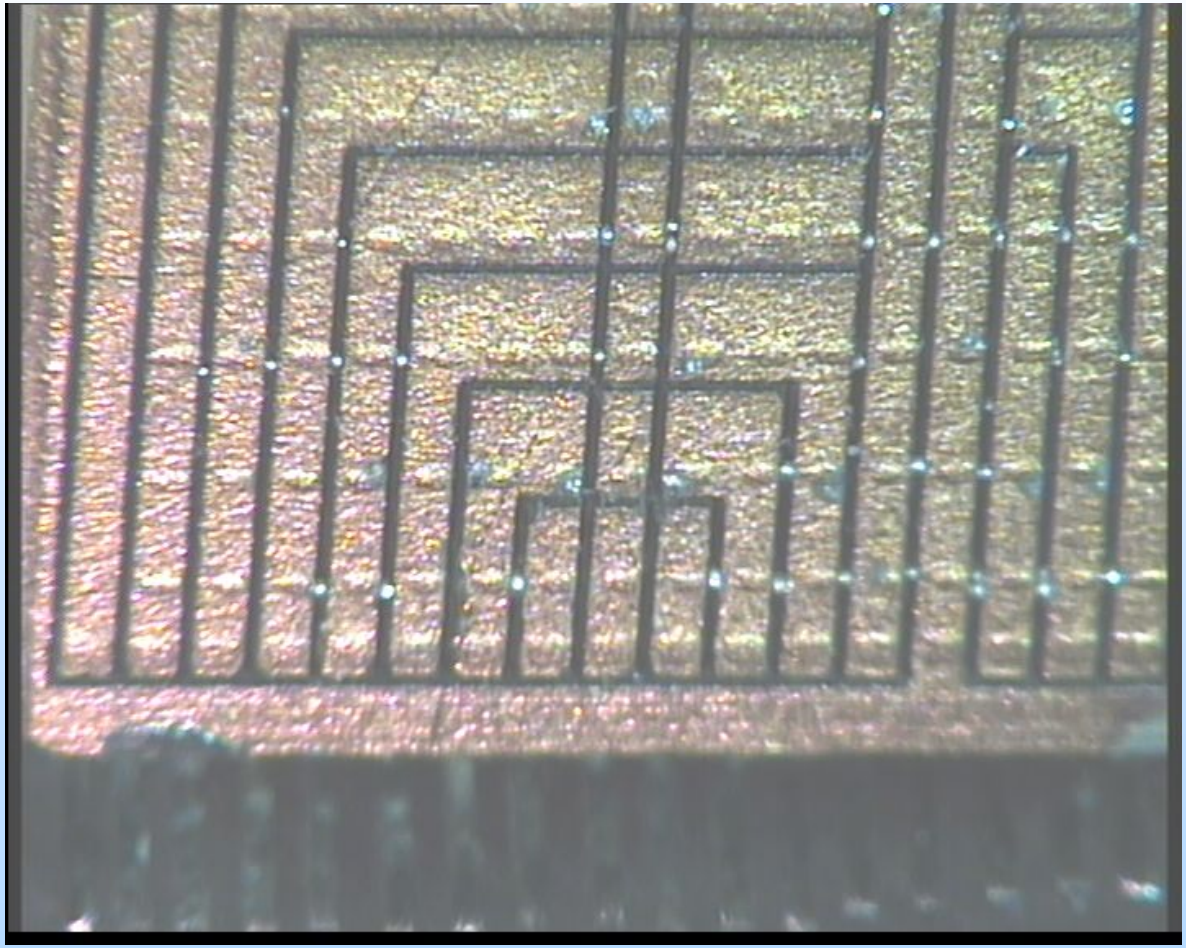


“String of Pearls”

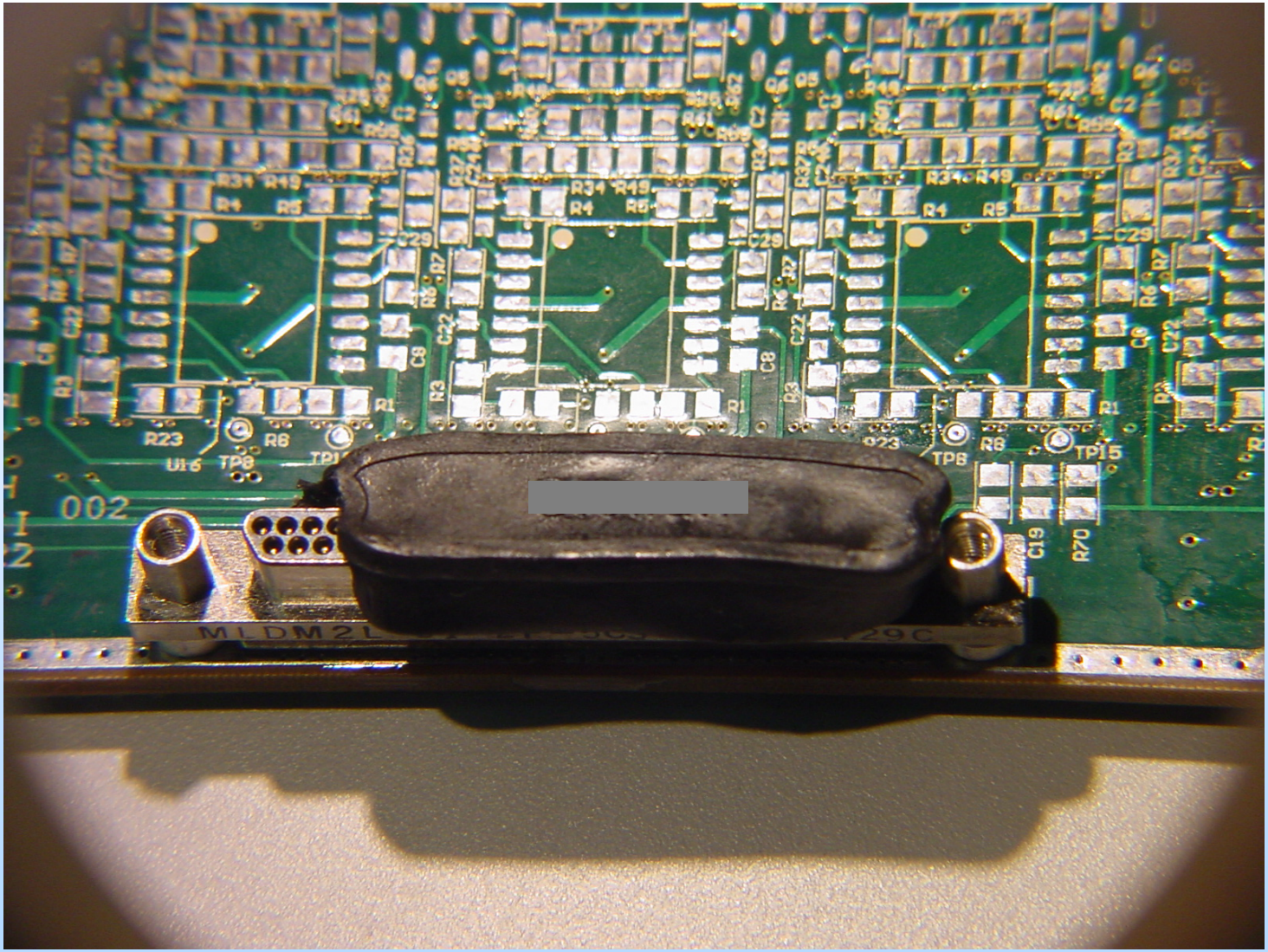
- **Giga-bit NAND flash, short-circuit failure**

- **Giga-bit NAND flash, short-circuit failure**
- The “solder balls” are a result of reflow
- The part was overheated during higher level assembly
- Solder used for internal interconnects between the stacked die reflowed
- Careful manual removal of solder balls and splashes returned part to functionality

<u>Thankfully, this is only an engineering grade unit.</u>



“Honey I Shrunk the Connector”



Summary

- Almost all of these failures were avoidable
- Small errors led to large consequences
- It is imperative to have good “toys”
- NEPP is an agency-wide program that endeavors to provide added-value to the greater aerospace community.
  - Always looking at the big picture (widest potential space use of evaluated technologies),
  - Never forgetting our partners, and
  - Attempting to do “less with less” (static budget versus rising costs).
- We invite your feedback and collaboration. Please visit our website (http://nepp.nasa.gov).
- Questions?