NASA Electronic Parts and
Packaging Program

Reliability Issues with New Technology Wet Tantalum Capacitors

Alexander Teverovsky

Dell Services Federal Government, Inc.

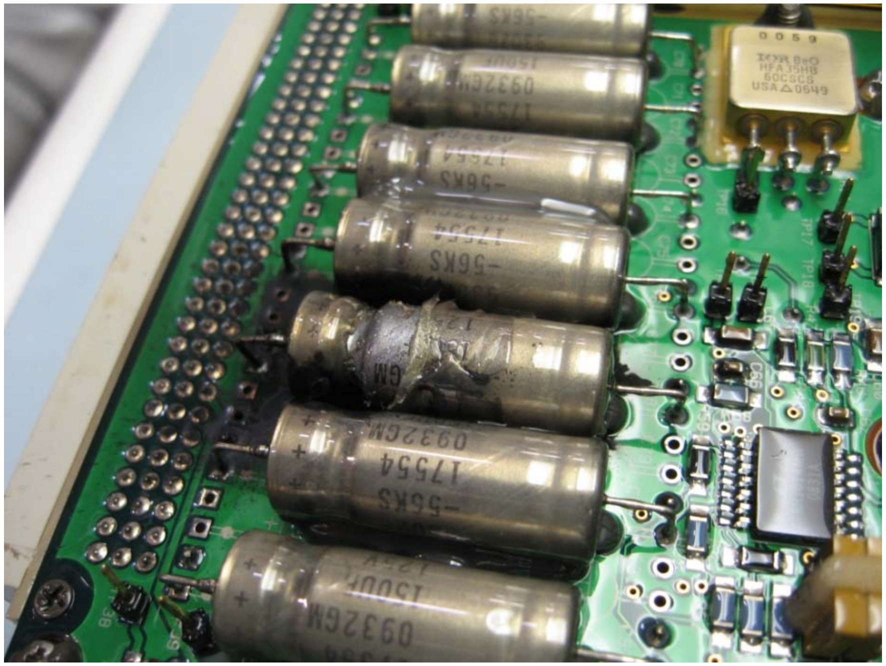
work performed for NASA Goddard Space Flight Center, Parts, Packaging, and Assembly Technologies Office, Code 562

Alexander.A.Teverovsky@nasa.gov

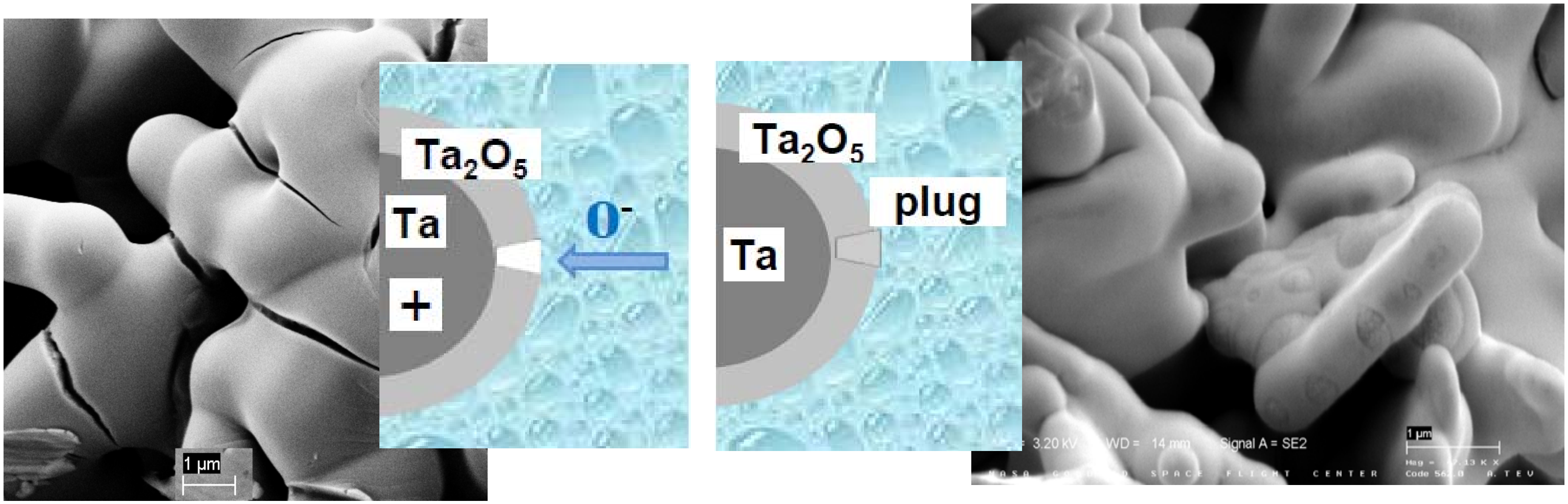
Presented by Alexander Teverovsky at the Components for Military & Space Electronics Conference & Exhibition (CMSE 2013), February 19-22, 2013, Los Angeles, CA, and published on nepp.nasa.gov.

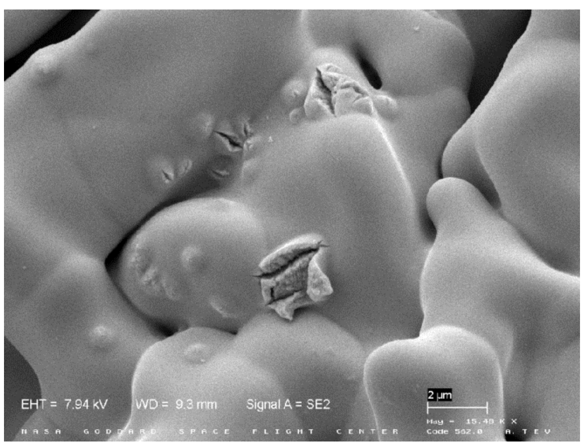
Outline

- Specifics of wet tantalum capacitors (WTC).
- New designs.
- Reverse bias operation.
- Random vibration testing.
- Failure modes and mechanisms.
- Conclusion and recommendations.
- Guidelines for selection, S&Q.



Self-Healing in Wet Tantalum Capacitors





- If Ta2O5 is damaged, anodic oxidation continues under normal, forward bias conditions resulting in oxide growth thus effectively eliminating the defect.
- Self-healing contributes substantially to the reliability of WTC – is it a panacea?

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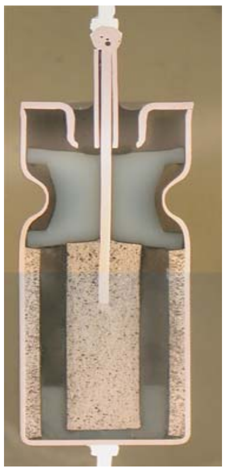
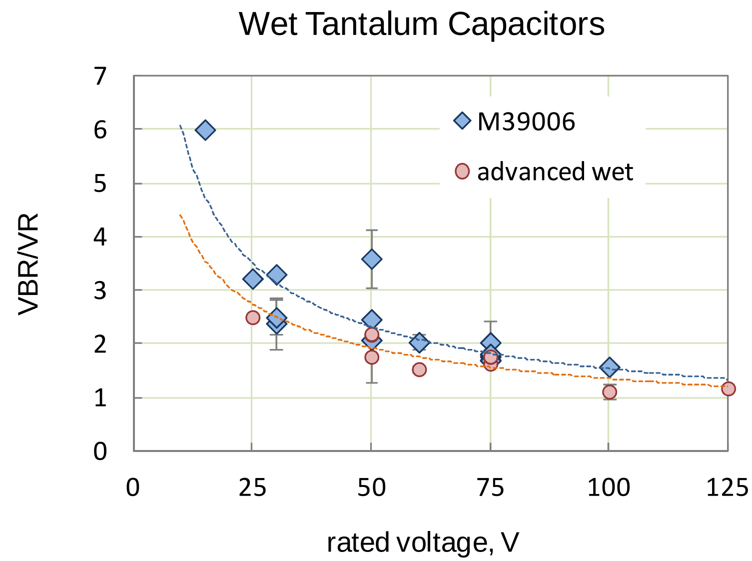
High Volumetric Efficiency WTC

M39006



DWG93026

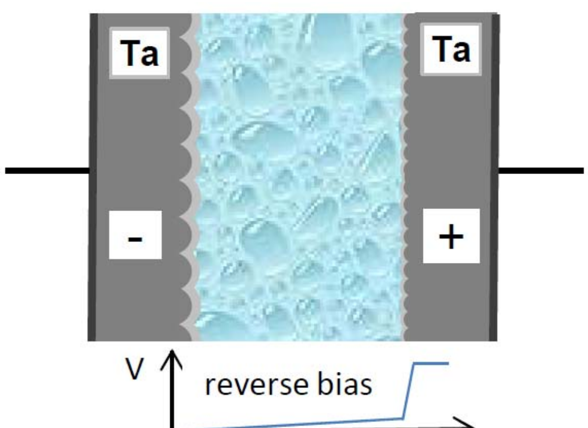


- Better performance of advanced WTC is achieved by reducing the thickness of the cathode layer, increasing the size of the slug, and using powder with a higher CV.
- Different manufacturers are using different cathode materials, e.g.: activated C/NbO; Pd/Cu; RuO2.
- Better performance does not come free.
- Reliability effect: reverse bias and mechanical stresses.

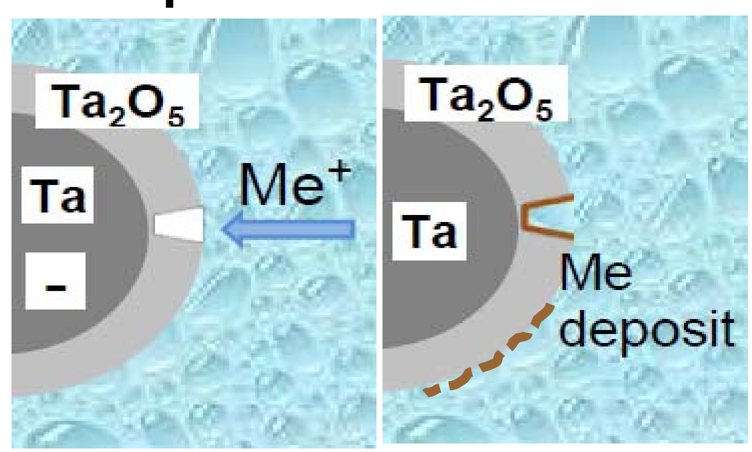
Should we Care about Reverse Bias (RB) for Unipolar Devices?

- Robustness to RB is needed to get additional margin for testing and unforeseen events.
- First tantalum capacitors in silver case had failures under low RB due to silver electrodepositing and dendrite growth.
- The use of a tantalum case and oxidized sintered Ta powder allowed to improve substantially the robustness against RB.
- New design WTC do not have protection against RB.
- 93026: RB < 1.5V and Q < 0.05C (?); 04005: no RB requirements.

Ta/Ta2O2 cathode



Electrodeposition of cathode metals



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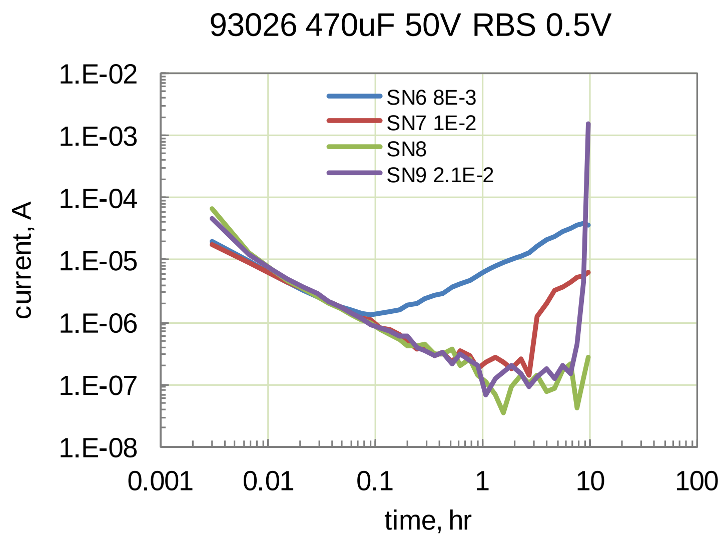
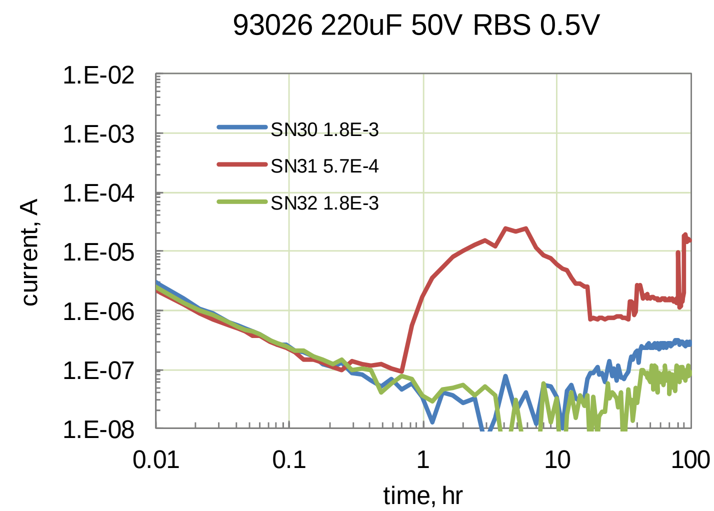
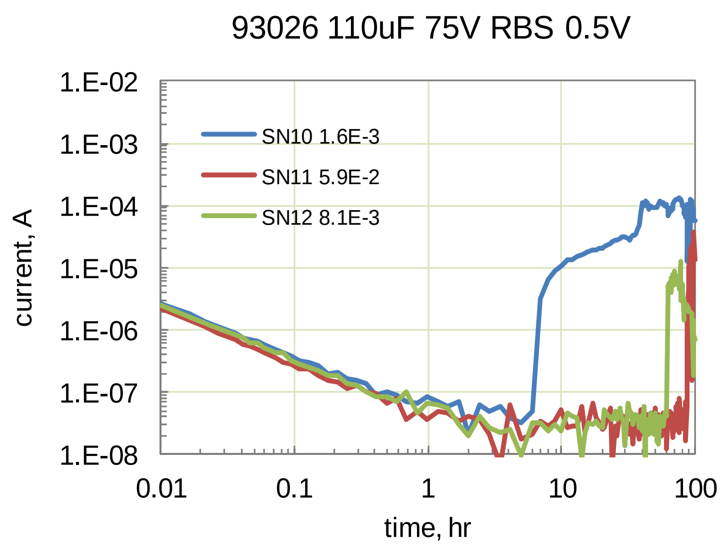
DWG#93026 RB Degradation at 0.5V

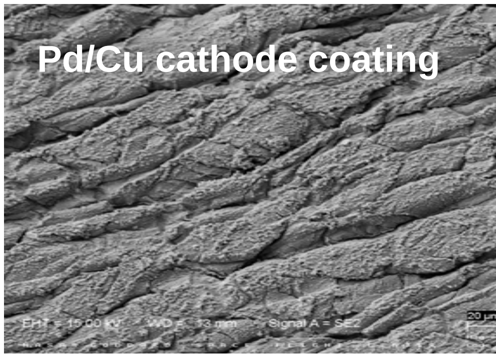


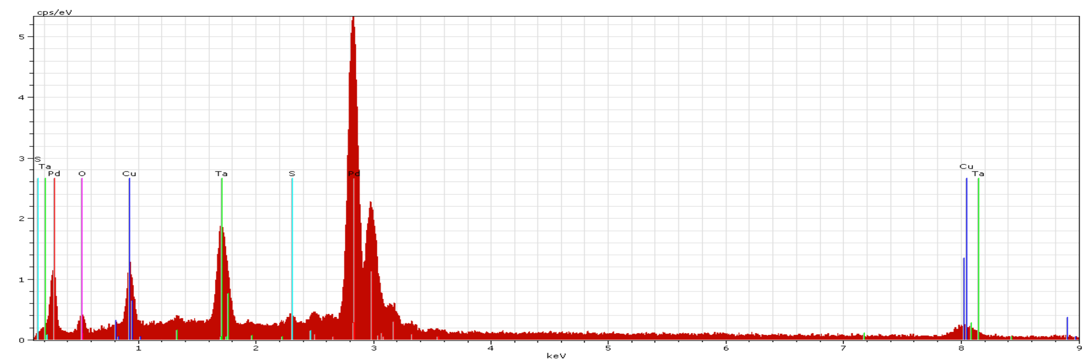


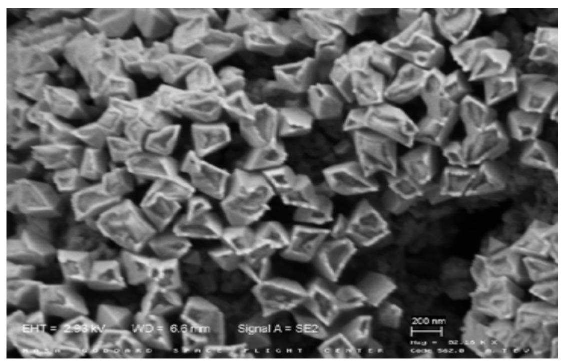


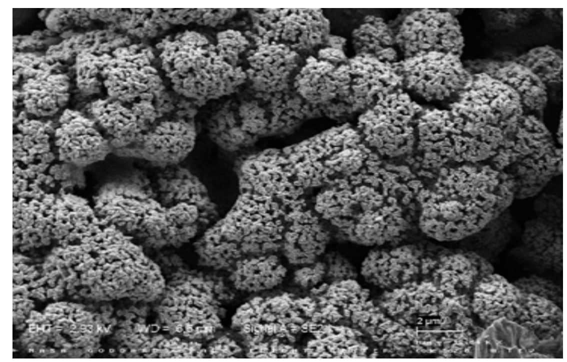
- In most cases the transfer charge is below the specified value of 0.05C.
- Time to failure varies from part-to part substantially.
- Failures might happen even at voltages as low as ~0.1V

Failure Mechanisms DWG93026 Mfr.B



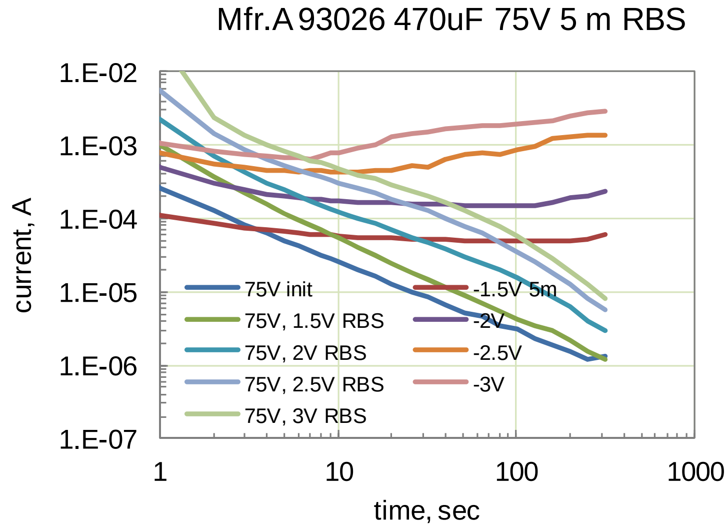


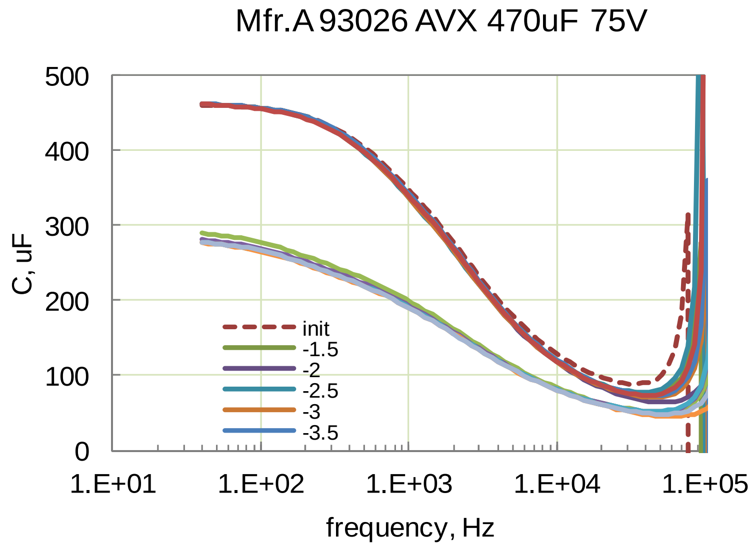




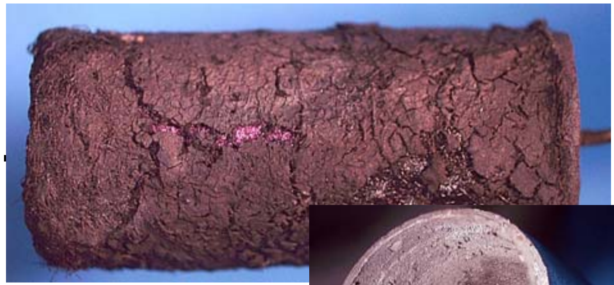
- Pd deposition on the surface of Ta2O5 reduces the barrier height and increases forward leakage currents.
- Electrodeposition at defects prevents self-healing.
- Degradation is reversible only partially.

DWG93026 470uF 75V Mfr.A, RBS





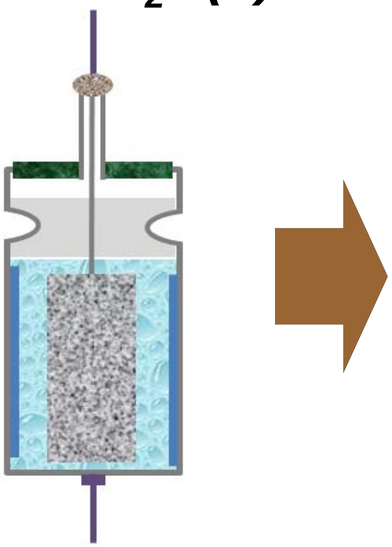
- ❑ RBS causes gradual degradation of RB and Forward Bias (FB) leakage currents.
- ❑ Capacitance decreases under RBS and then stabilizes.
- ❑ The loss of capacitance might be due to electropolishing or detachment of the cathode layer.

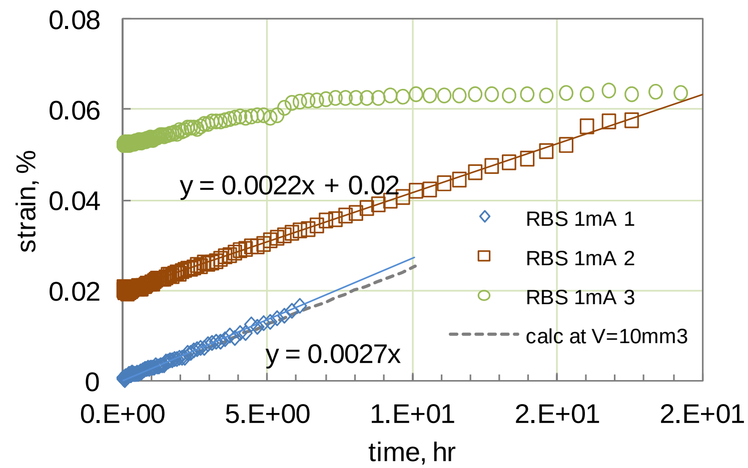


DWG93026 Bulging

H_2 generation at cathode:

$2e^- + 2H_2O(L) \Rightarrow H_2(g) + 2OH^-(aq)$





$$n = \frac{I \times t}{z \times F} \quad P = n \times \frac{RT}{V} \quad \varepsilon = \frac{P \times r}{E \times h}$$

- Temperature and deformation of the case were measured using flexible sensors.
- Strain increases linearly with time due to the pressure building up.
- Strain ~0.07% corresponds to a pressure of dozens of atmospheres.

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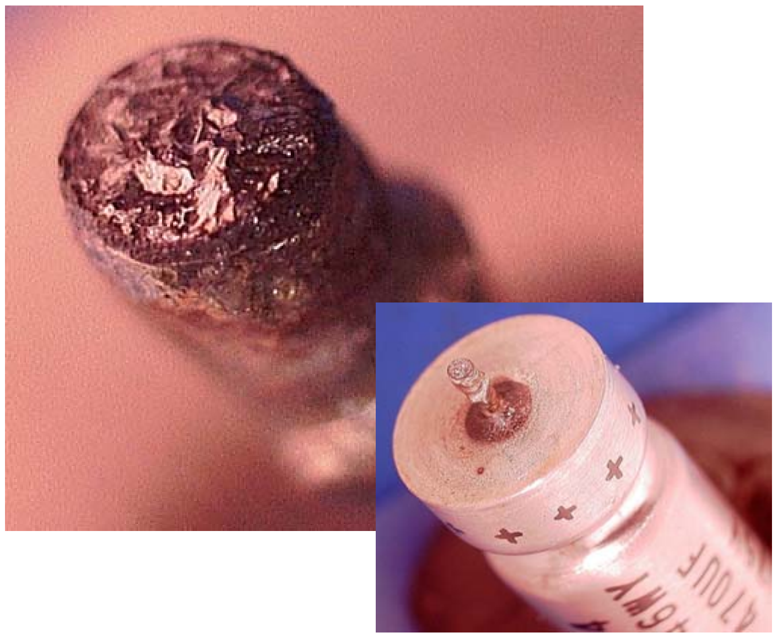
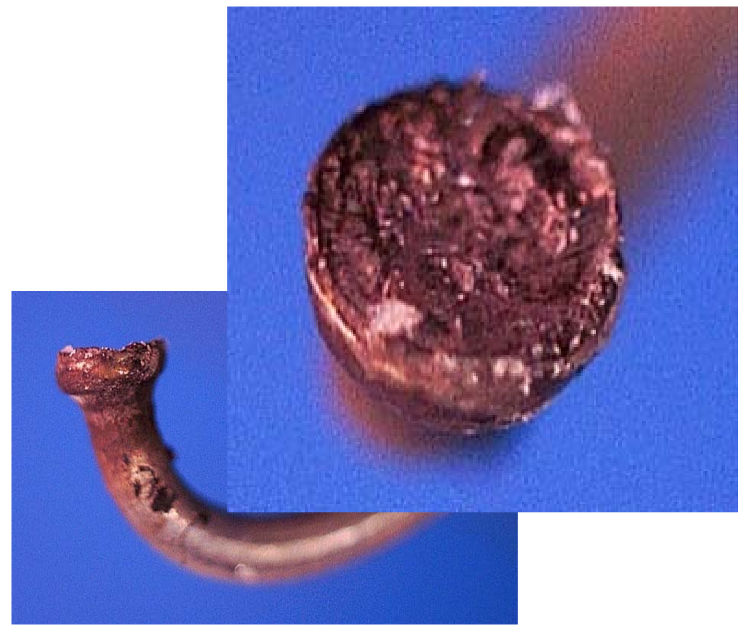
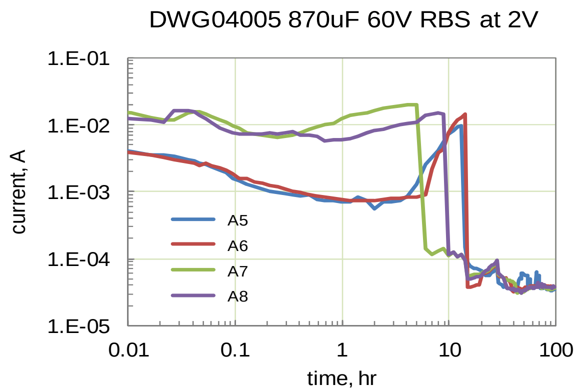
DWG93026 470uF 75V Mfr.A RBS Failure

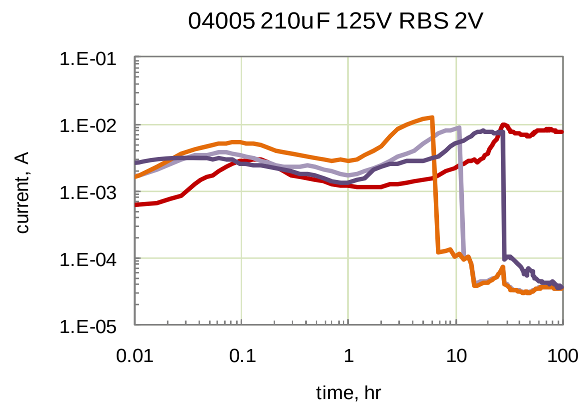



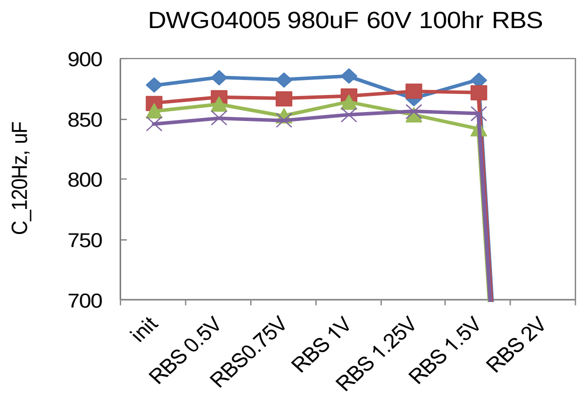
SN19 failed after 100hr 2V RBS due to lead fell-off caused by electrolyte leak.

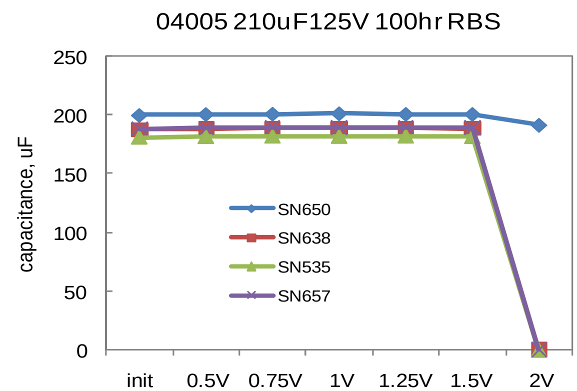
- Pressure deforms the case, forces electrolyte above the Teflon bushing, and causes corrosion of the weld.

RBS in Button-Style Capacitors



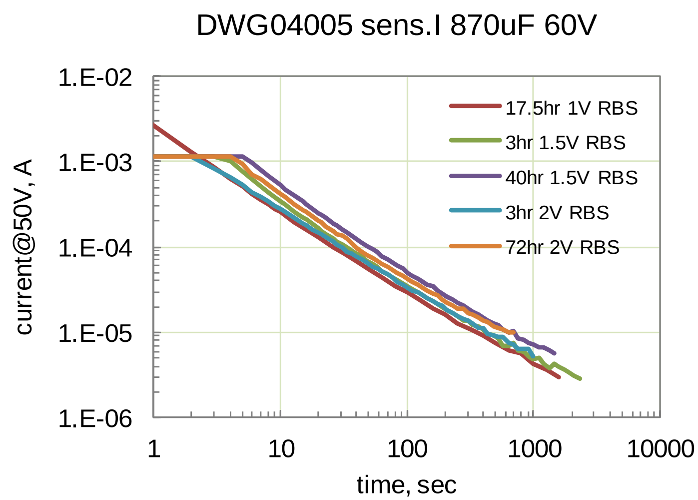


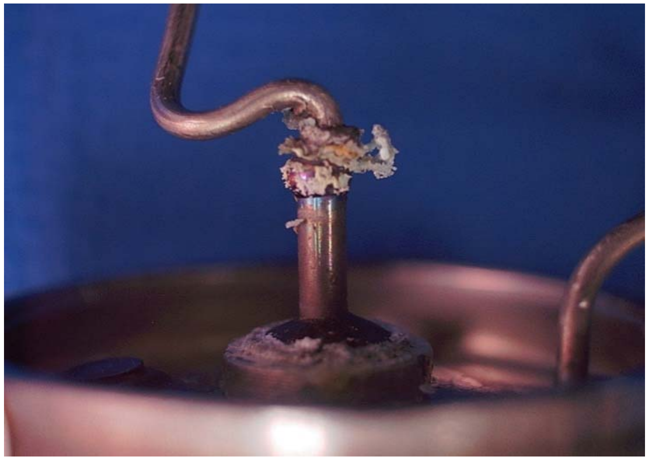


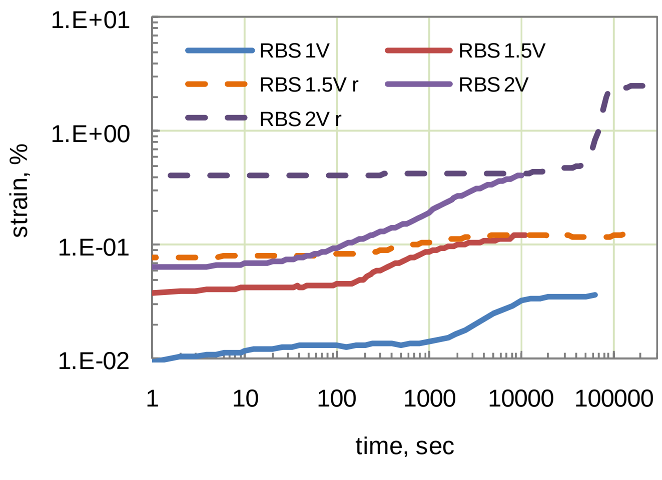


- DWG04005 capacitors feature a sharp decrease in RB current and open circuit failure mode.

Strain in DWG04005 980uF 60V, RBS

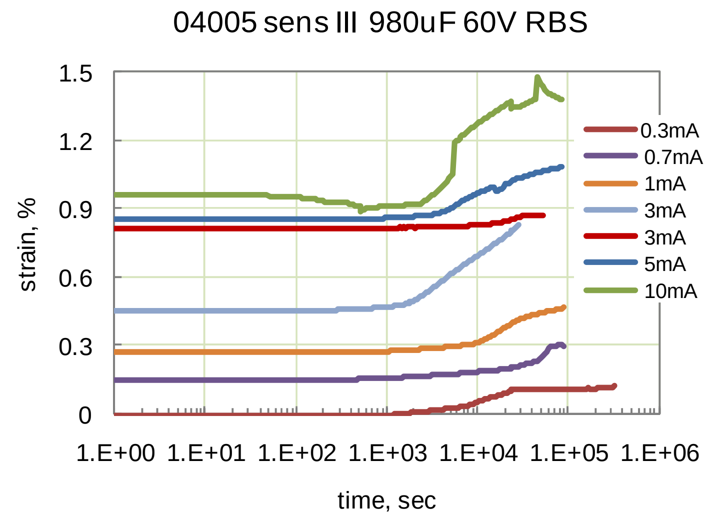


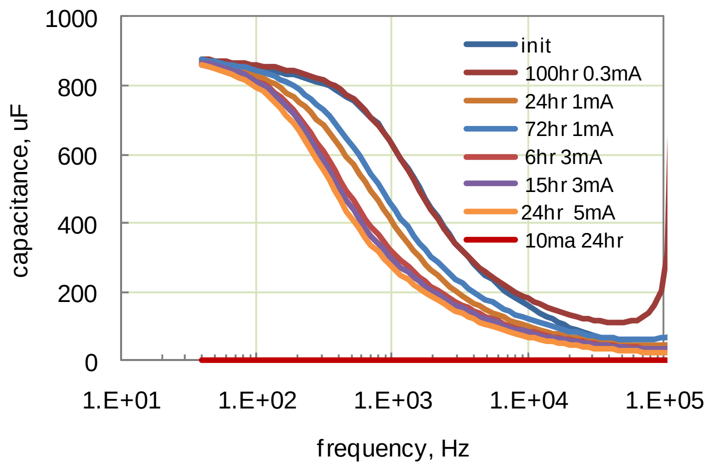




- ❑ Pressure starts building up after a few sec at 1V.
- ❑ Pressure remains in the case when parts are unbiased and can cause electrolyte leak and corrosion.
- ❑ DCL did not degrade after 100hr of 2V RBS; whereas C and ESR fail.
- ❑ Strain ~3% => pressure up to 50 atm.

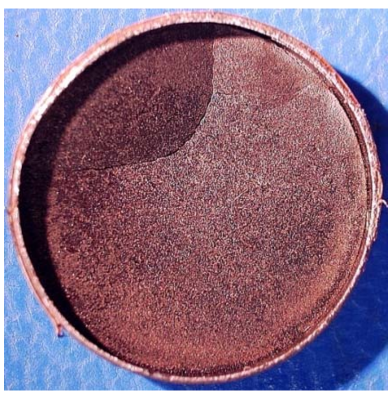
Strain in DWG04005 980uF 60V, RBS at Constant Current

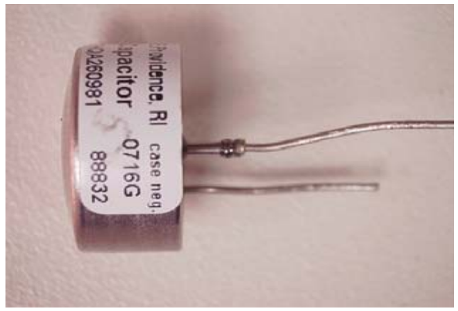


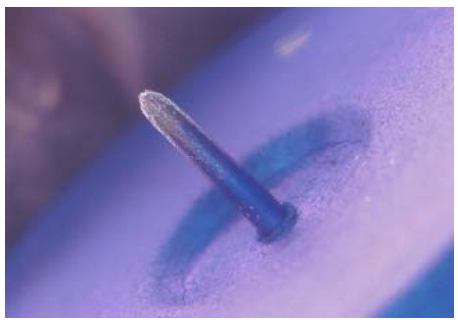


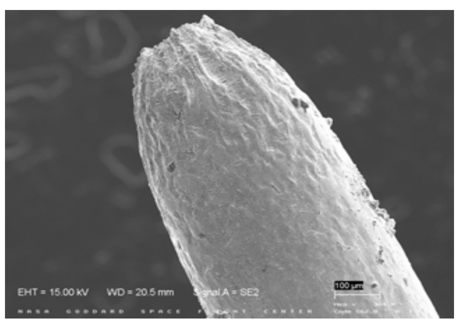
- ❑ Strain accumulates with each cycle.
- ❑ Stabilization of pressure with time is likely due to voltage drop below the threshold level.
- ❑ FB currents do not degrade substantially.
- ❑ Decrease of roll-off frequency with RBS
- ❑ Failures in an open circuit mode.

DWG04005 Failure Mechanism





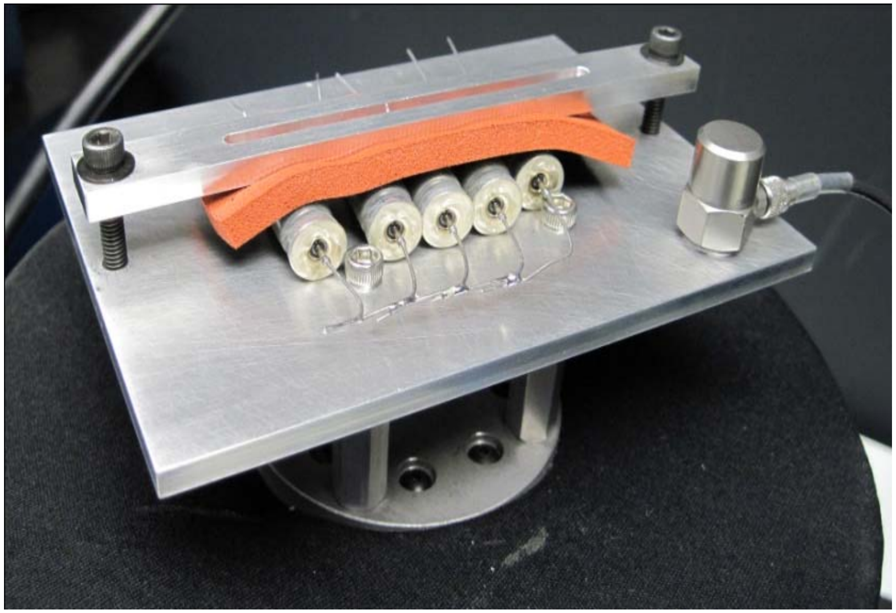




- Internal pressure causes bulging.
- Bulging strains the wire that fractures eventually. (max wire deformation ~ 0.25 mm; deformation of a clamped 20 mil membrane at 50 atm~0.23 mm)
- The absence of a Teflon gasket facilitates electrolyte leakage.
- Wire fracture and electrolyte leakage cause open circuit failures.

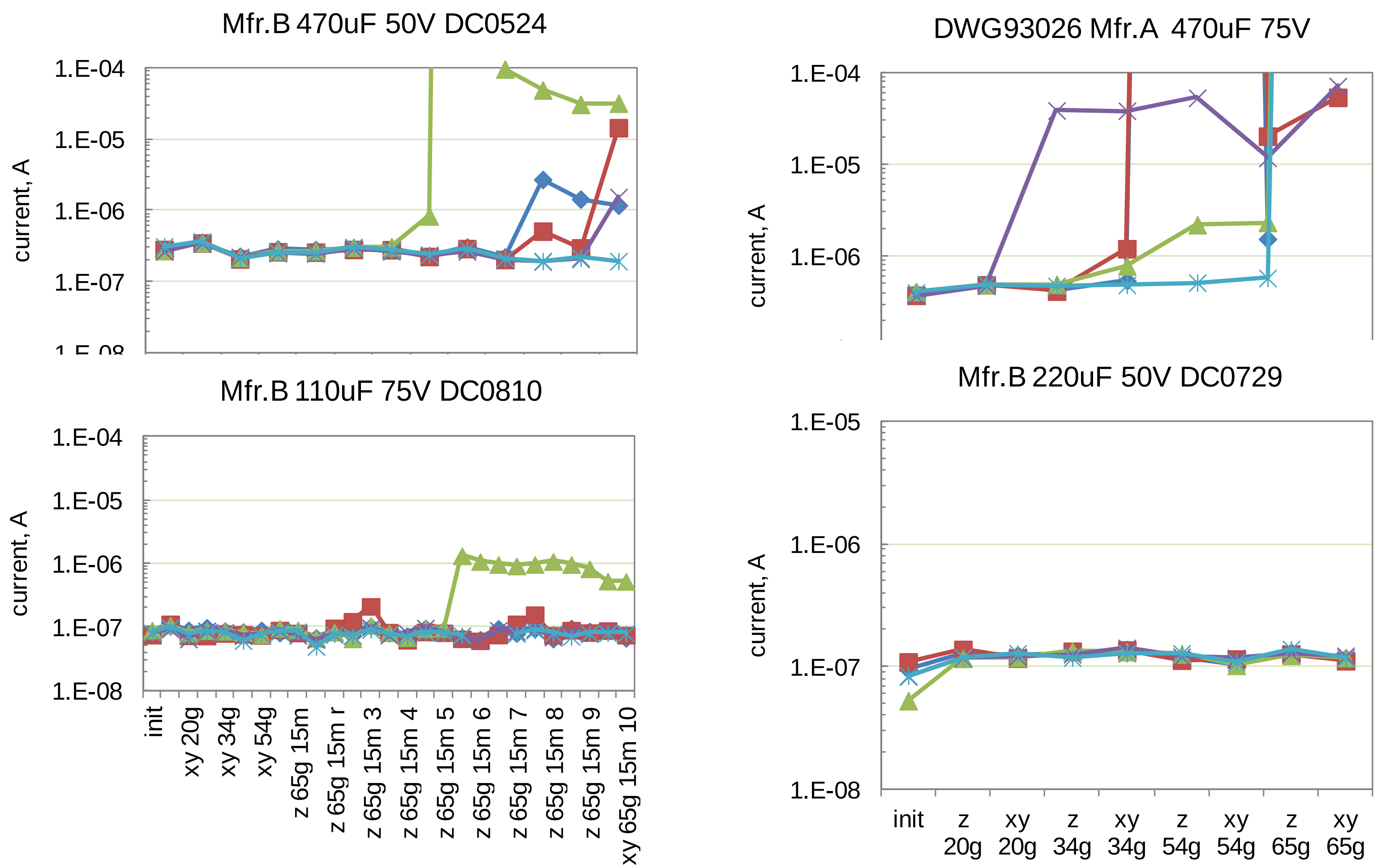
Random Vibration Test

- Capacitors per DWG#93026 and #04005 are qualified to 20 g sin high frequency vibration only.
  - Sample size is not set (in some cases 2 samples only are tested).
  - Test conditions are not specific.
  - Random vibration testing is not required and is performed only if specified by the purchase order.



- Random vibration test is more appropriate for space applications than HF sinusoidal vibration, and MARs for most projects require box-level random vibration testing at 14.1 G_{rms}.

Random Vibration Step Stress Testing



Different part types have failures from 20 to >65 G_{rms}.

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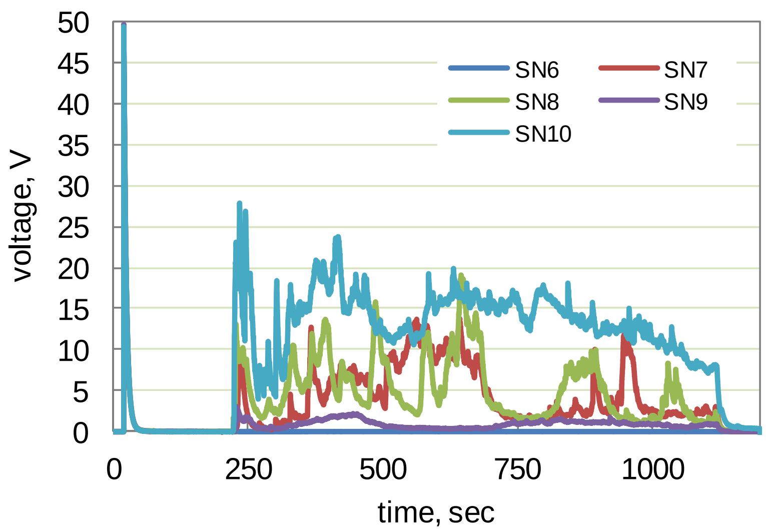
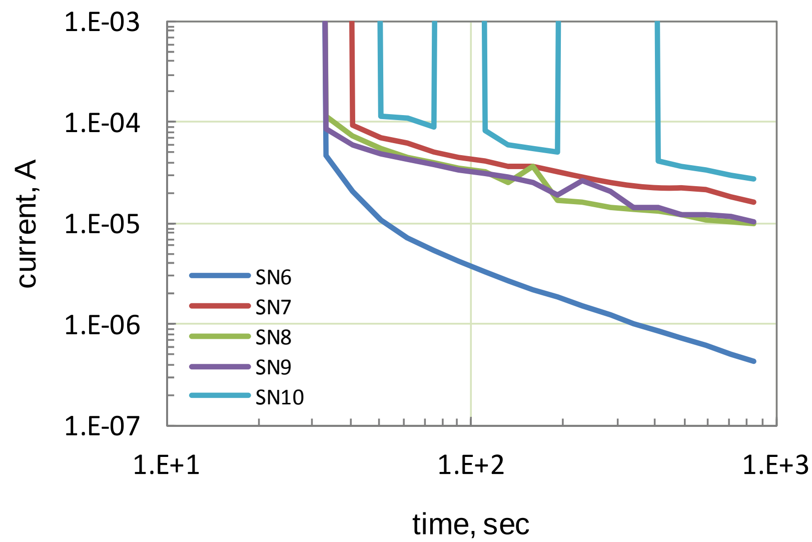
Failures DuringTesting at 10.7 G_{rms}

DWG93026 470uF 75V at 10.7 rms g



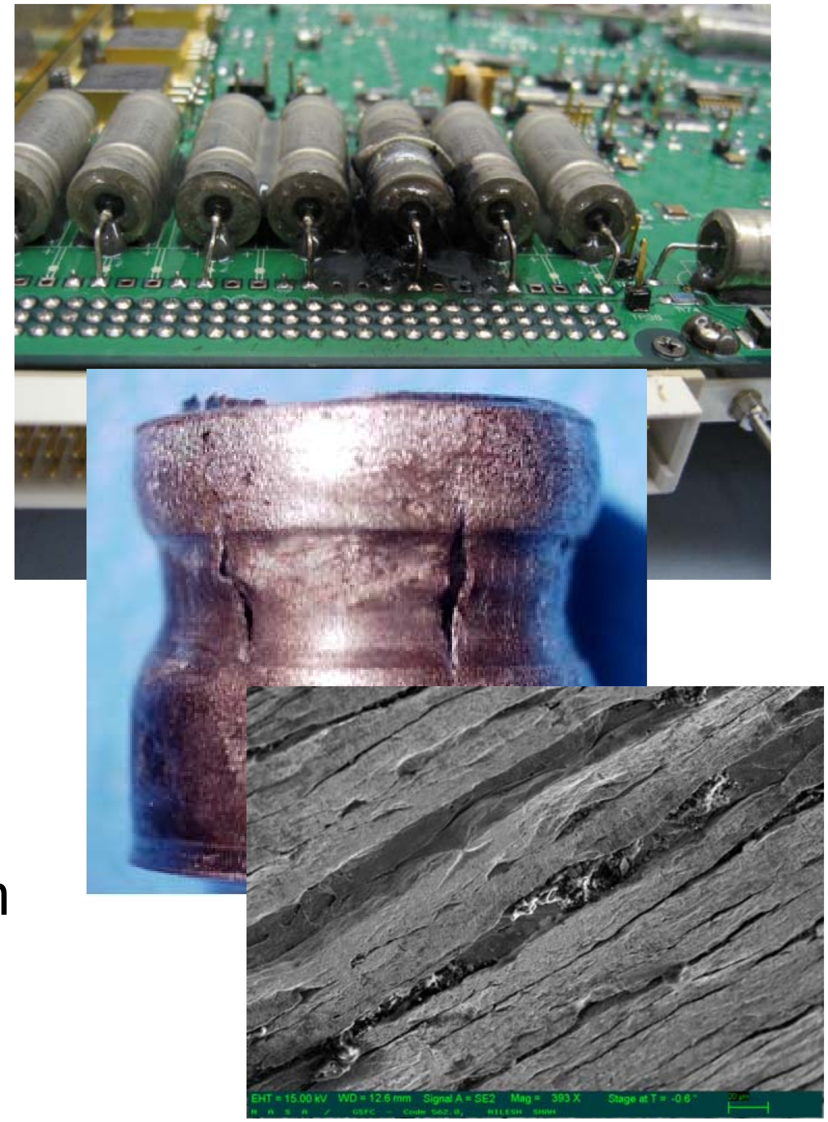
DVG93026 470uF 75V after 10.7 rms g



Some DWG#93026 parts can fail at vibration levels that are below MAR requirements.

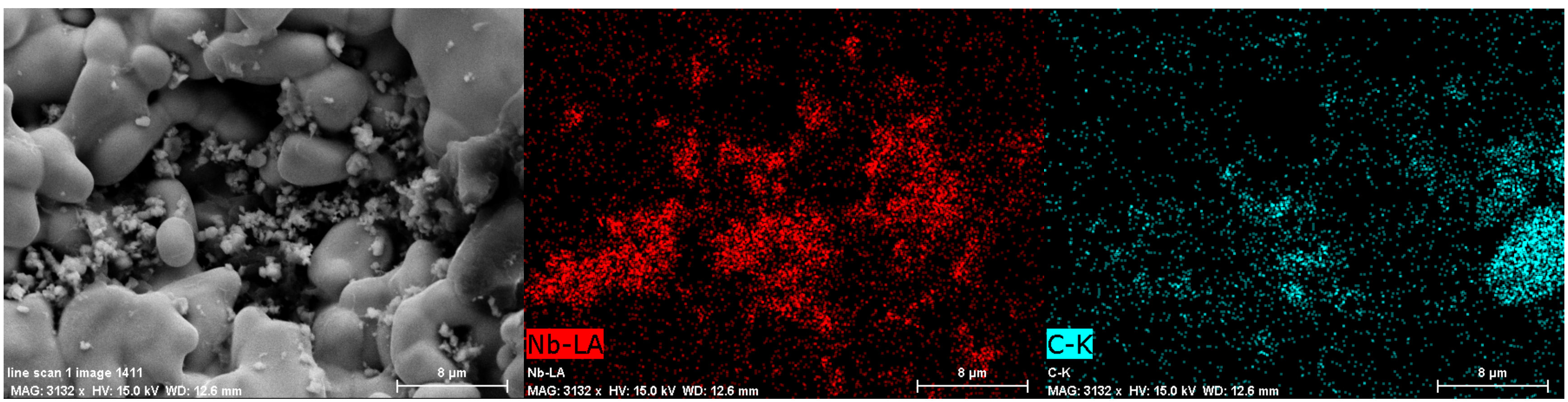
A History Case

- Several anomalies have been observed during thermal vacuum testing. However, at the end of the testing the unit operated normally.
- Post-testing internal examinations revealed damaged sleeve, discoloration and charring of conformal coating around one of the WTCs.
- The cracks were due to stresses caused by the building-up of gas pressure in the case and hydrogen embrittlement of tantalum at cold work areas.



Particles in the Slug

- Failures during vibration are likely caused by NbO and carbon particles penetrating inside the slug.
- Under mechanical stresses these particles might create local stresses sufficient to cause damage to the dielectric and increase leakage current.



Conclusion

- DWG#93026 and 04005 parts might fail at low-voltage (0.5V and less) RB conditions and random vibration as low as 10.7 G_{rms}.
- The probability of failure does not depend on rated voltage.
- RB and vibration can result in increased leakage currents, internal gas pressure, case fractures, electrolyte leak, and corrosion.
- Parts with Pd-based cathode appeared to be more sensitive to RB, whereas parts with Nb-based cathode are more sensitive to vibration.
- Manufacturers are working on new designs to improve reliability.
- Advance WTCs can self-heal, are resilient to environmental stresses, but not to the degree of M39006 capacitors. To operate reliably, the robustness against mechanical stress (random vibration at 20 G_{rms}) and RB (to 1.5V at 85C) should be verified.
- Guidelines for selection, S&Q and DPA of the WTC are suggested.

Guidelines

I. Scope

II. Background

III. Failure rate

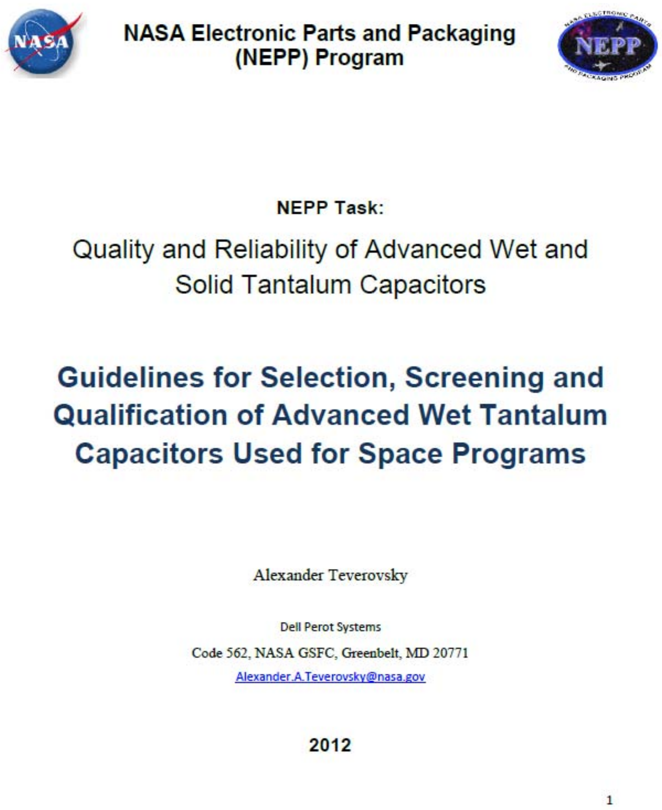
IV. Construction analysis/DPA

V. Lot acceptance testing

VI. Qualification testing

VII. Freshness policy

VIII. Derating



NASA Electronic Parts and Packaging (NEPP) Program

NEPP Task:

Quality and Reliability of Advanced Wet and Solid Tantalum Capacitors

Guidelines for Selection, Screening and Qualification of Advanced Wet Tantalum Capacitors Used for Space Programs

Alexander Teverovsky

Dell Perot Systems

Code 562, NASA GSFC, Greenbelt, MD 20771

Alexander.A.Teverovsky@nasa.gov

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