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Tantalum Capacitors: New Trends and Old Myths

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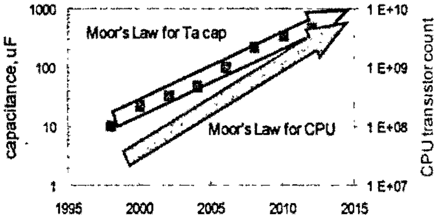
Myth 1: Ta Caps are Conservative Parts

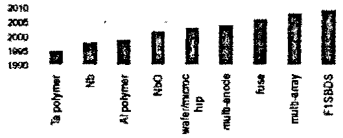
Facts:

- **Time and place of development of solid Ta capacitors and transistors is the same: Bell Labs, mid 1950s.**
- **Moor's law is applicable to tantalum capacitors.**
- **Competition with other technologies forces innovations.**

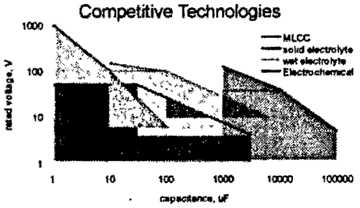
AVX 6.3V capacitors in case 3528, h=1.2mm

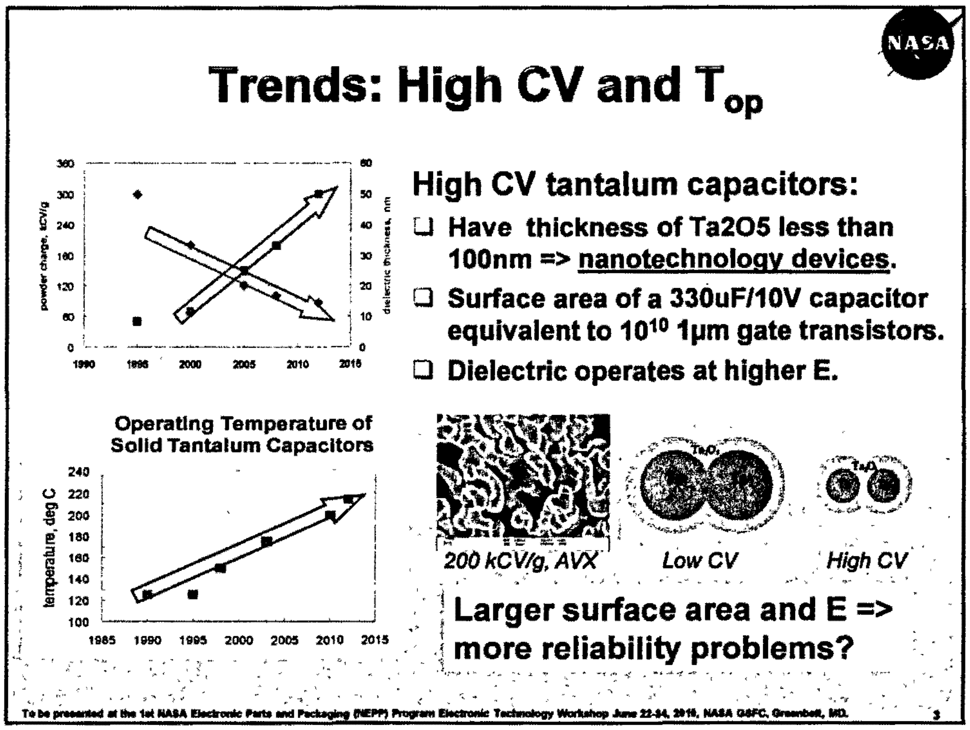


New Technologies in Solid Chip Electrolytic Capacitors



Competitive Technologies





Trends: High CV and T_{op}

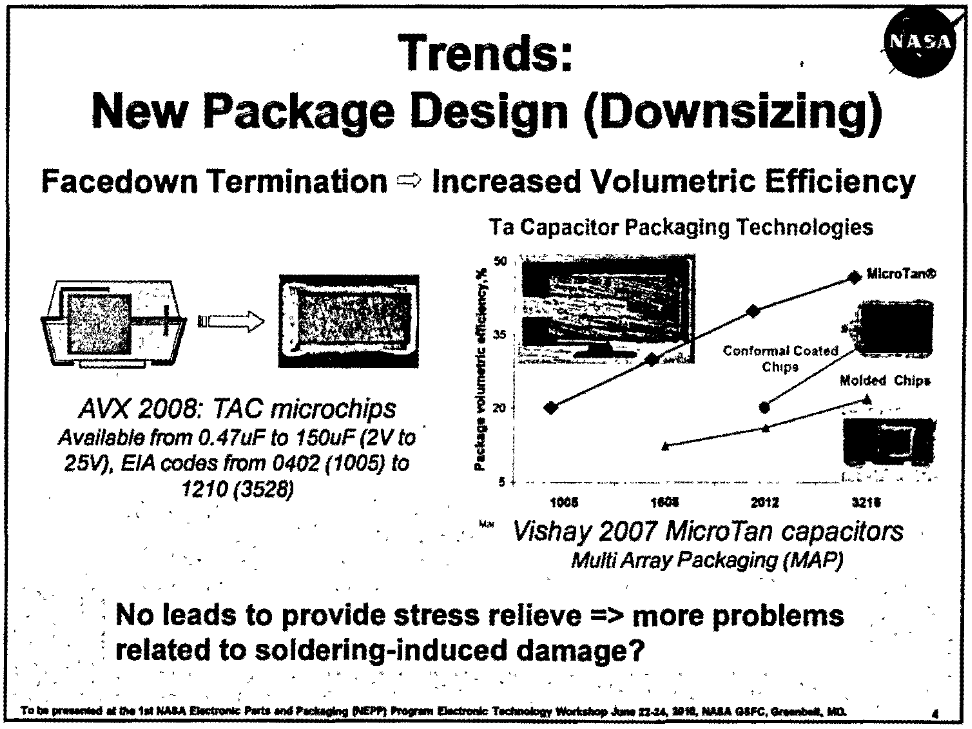
High CV tantalum capacitors:

- ☐ Have thickness of Ta2O5 less than 100nm => <u>nanotechnology devices</u>.
- ☐ Surface area of a 330uF/10V capacitor equivalent to 10^{10} 1µm gate transistors.
- ☐ Dielectric operates at higher E.

Operating Temperature of Solid Tantalum Capacitors

200 kCV/g, AVX *Low CV* *High CV*

Larger surface area and E => more reliability problems?



Trends:
New Package Design (Downsizing)

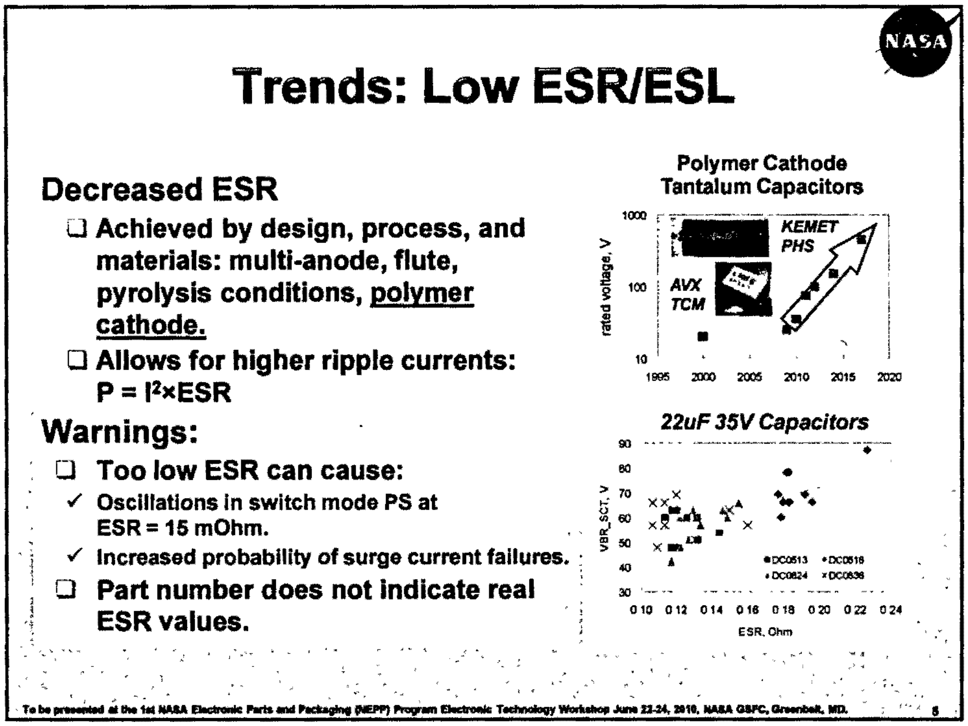
Facedown Termination ⇨ Increased Volumetric Efficiency

AVX 2008: TAC microchips
Available from 0.47uF to 150uF (2V to 25V), EIA codes from 0402 (1005) to 1210 (3528)

Ta Capacitor Packaging Technologies

Vishay 2007 MicroTan capacitors
Multi Array Packaging (MAP)

No leads to provide stress relieve => more problems related to soldering-induced damage?



Trends: Low ESR/ESL

Decreased ESR

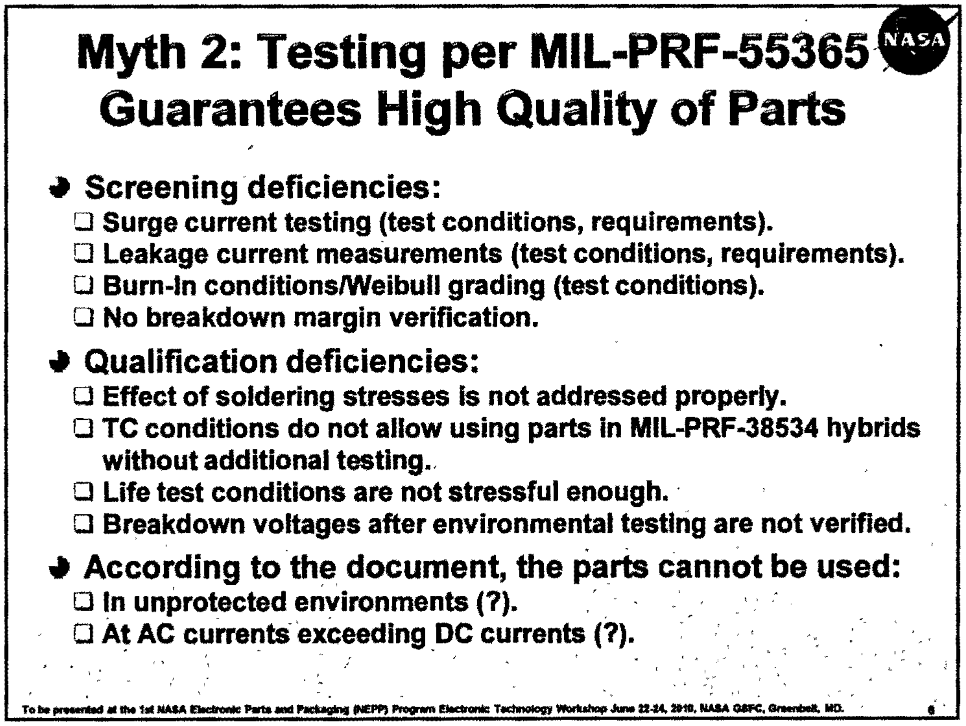
- ☐ Achieved by design, process, and materials: multi-anode, flute, pyrolysis conditions, polymer cathode.
- ☐ Allows for higher ripple currents: $P = I^2 \times ESR$

Warnings:

- ☐ Too low ESR can cause:
  - ✓ Oscillations in switch mode PS at ESR = 15 mOhm.
  - ✓ Increased probability of surge current failures.
- ☐ Part number does not indicate real ESR values.

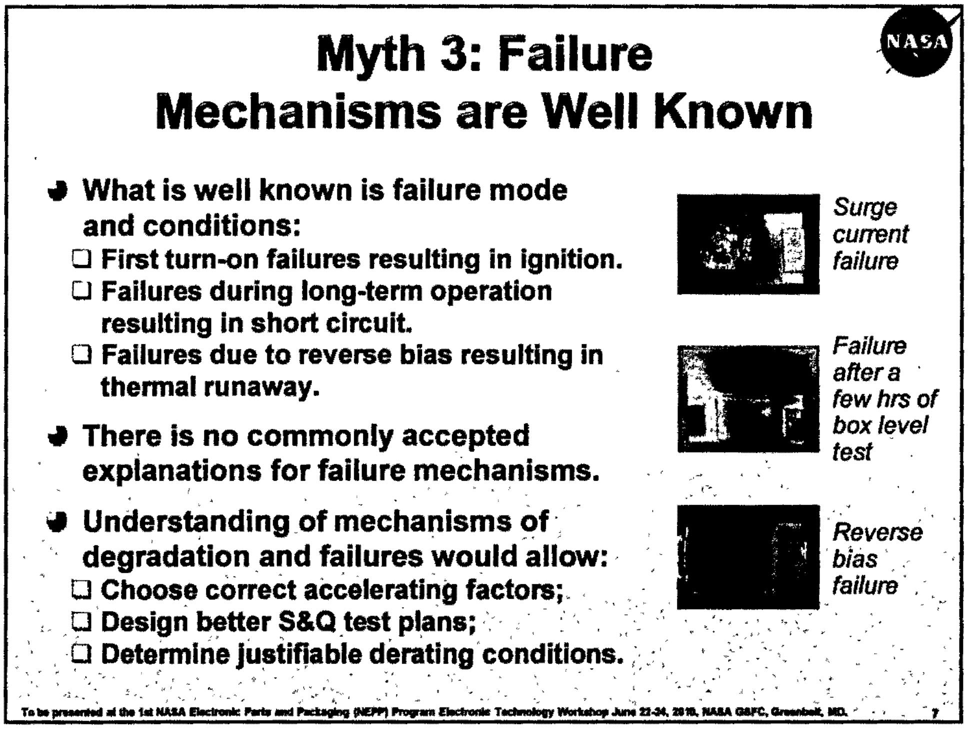
Polymer Cathode Tantalum Capacitors

22uF 35V Capacitors



Myth 2: Testing per MIL-PRF-55365 Guarantees High Quality of Parts

- Screening deficiencies:
  - ☐ Surge current testing (test conditions, requirements).
  - ☐ Leakage current measurements (test conditions, requirements).
  - ☐ Burn-In conditions/Weibull grading (test conditions).
  - ☐ No breakdown margin verification.
- Qualification deficiencies:
  - ☐ Effect of soldering stresses is not addressed properly.
  - ☐ TC conditions do not allow using parts in MIL-PRF-38534 hybrids without additional testing.
  - ☐ Life test conditions are not stressful enough.
  - ☐ Breakdown voltages after environmental testing are not verified.
- According to the document, the parts cannot be used:
  - ☐ In unprotected environments (?).
  - ☐ At AC currents exceeding DC currents (?).



Myth 3: Failure Mechanisms are Well Known

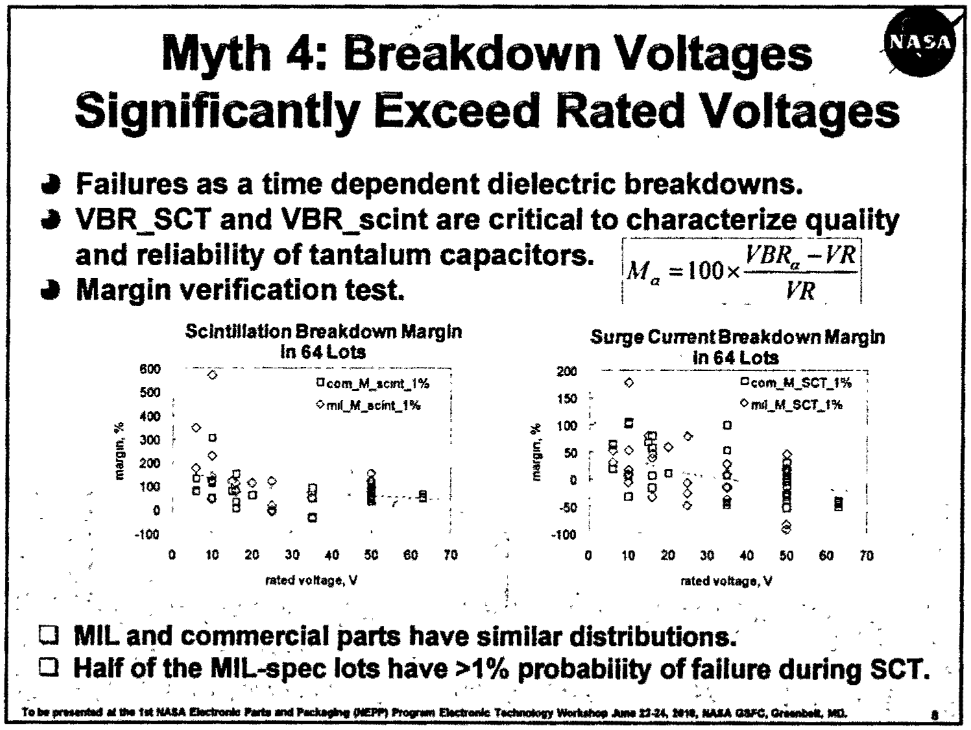
- What is well known is failure mode and conditions:
  - ☐ First turn-on failures resulting in ignition.
  - ☐ Failures during long-term operation resulting in short circuit.
  - ☐ Failures due to reverse bias resulting in thermal runaway.
- There is no commonly accepted explanations for failure mechanisms.
- Understanding of mechanisms of degradation and failures would allow:
  - ☐ Choose correct accelerating factors;
  - ☐ Design better S&Q test plans;
  - ☐ Determine justifiable derating conditions.

Surge current failure

Failure after a few hrs of box level test

Reverse bias failure

To be presented at the 1st NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 22-24, 2010, NASA GSFC, Greenbelt, MD.



Myth 4: Breakdown Voltages Significantly Exceed Rated Voltages

- Failures as a time dependent dielectric breakdowns.
- VBR_SCT and VBR_scint are critical to characterize quality and reliability of tantalum capacitors.
- Margin verification test.

$$M_a = 100 \times \frac{VBR_a - VR}{VR}$$

Scintillation Breakdown Margin in 64 Lots

Surge Current Breakdown Margin in 64 Lots

- ☐ MIL and commercial parts have similar distributions.
- ☐ Half of the MIL-spec lots have >1% probability of failure during SCT.

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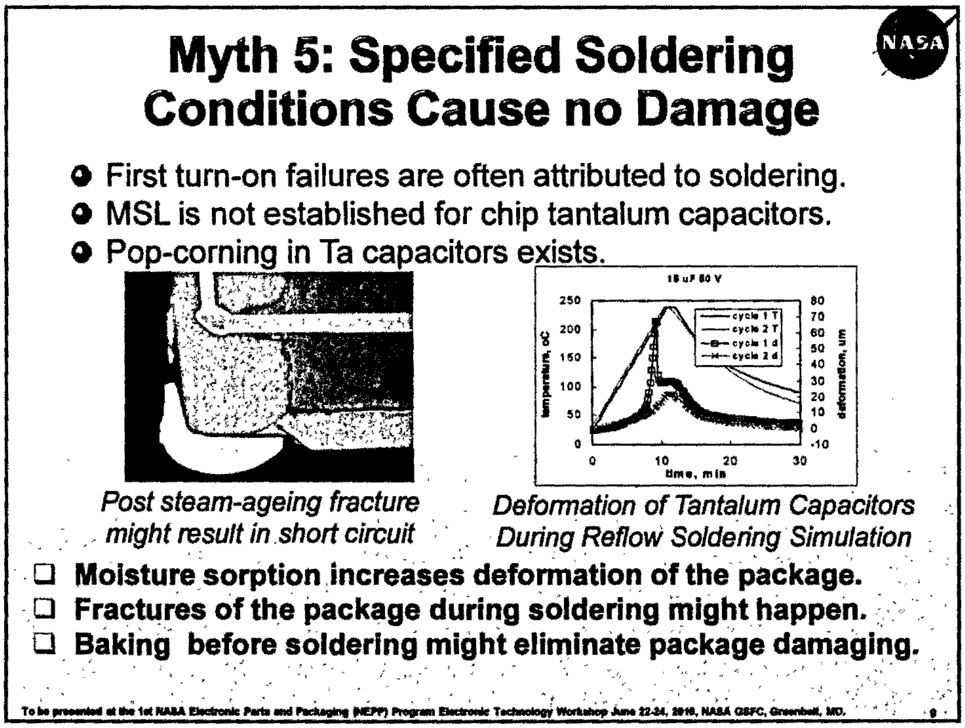


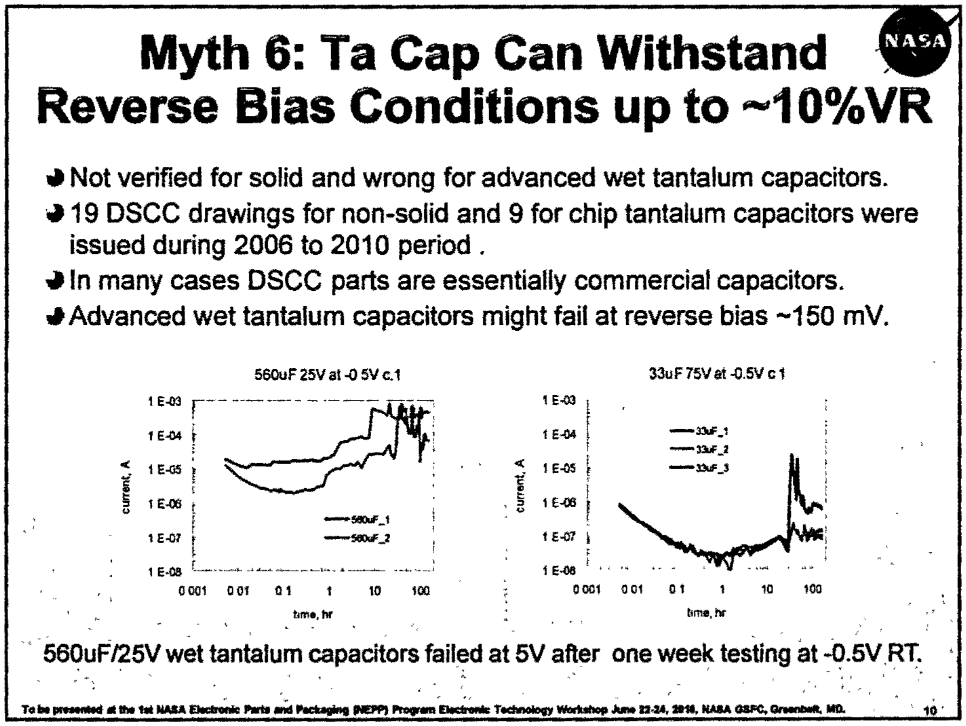
Myth 5: Specified Soldering Conditions Cause no Damage

- First turn-on failures are often attributed to soldering.
- MSL is not established for chip tantalum capacitors.
- Pop-corning in Ta capacitors exists.

Post steam-ageing fracture might result in short circuit

Deformation of Tantalum Capacitors During Reflow Soldering Simulation

- ☐ **Moisture sorption increases deformation of the package.**
- ☐ **Fractures of the package during soldering might happen.**
- ☐ **Baking before soldering might eliminate package damaging.**



Myth 6: Ta Cap Can Withstand Reverse Bias Conditions up to ~10%VR

- Not verified for solid and wrong for advanced wet tantalum capacitors.
- 19 DSCC drawings for non-solid and 9 for chip tantalum capacitors were issued during 2006 to 2010 period .
- In many cases DSCC parts are essentially commercial capacitors.
- Advanced wet tantalum capacitors might fail at reverse bias ~150 mV.

560uF/25V wet tantalum capacitors failed at 5V after one week testing at -0.5V RT.

Reliability of High-Voltage Tantalum Capacitors

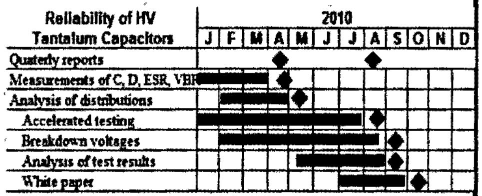
Description:

Based on test results and methodology developed during 2009 task, reliability of new high voltage tantalum capacitors will be assessed using accelerated life testing. Safety margins for scintillation and surge current breakdown voltages will be evaluated for different types of tantalum capacitors. Degradation of leakage currents and failures will be investigated, the mechanism of failures will be discussed, and derating requirements will be suggested.

FY10 Plans:

- ☐ *Different types of 50V and 63V military and commercial capacitors with comparable characteristics, but obtained from different vendors, will be used in this study.*
- ☐ *Distributions of AC and DC characteristics of the parts, including surge current and scintillation breakdown voltages, and leakage currents will be analyzed.*
- ☐ *A monitored highly accelerated life testing at different stress levels will be used to assess accelerating factors, compare reliability of different types of high-voltage capacitors, and assess accelerating factors.*
- ☐ *The existing screening, qualification, and derating requirements for high-voltage capacitors will be analyzed.*

Schedule:

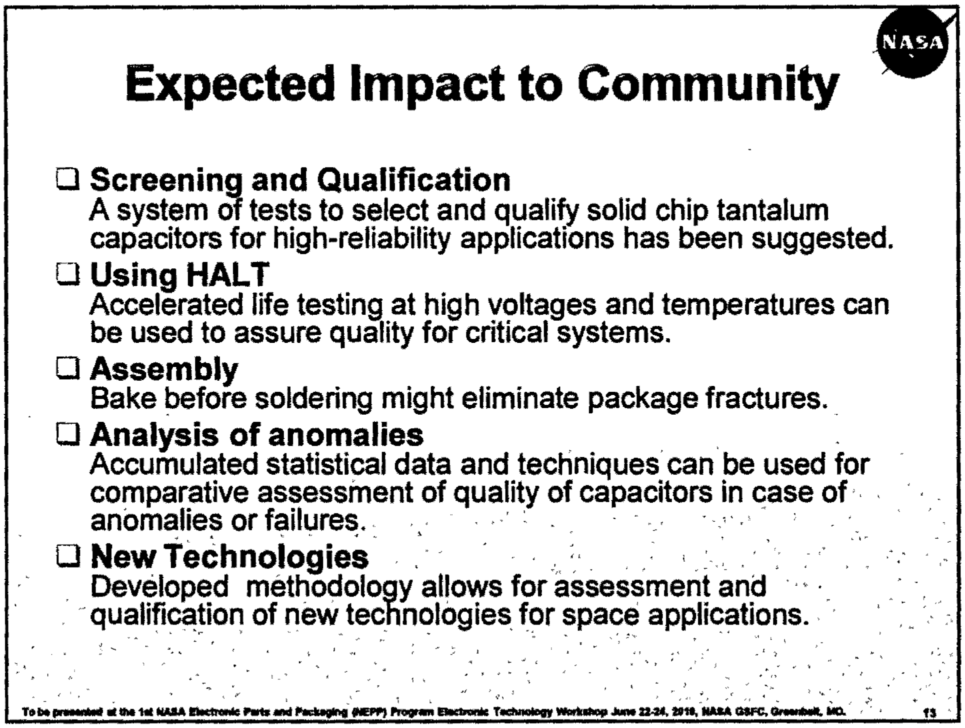


Deliverables:

- ☐ *The deliverable is a report (white paper) containing analysis of literature data and test results obtained in this study.*
- ☐ *Recommendations for screening, qualification, and derating requirements.*
- ☐ *Results of analysis and reliability qualification approaches will be discussed with manufacturers of capacitors, presented at CARTS and other conferences, and published in IEEE Transactions.*

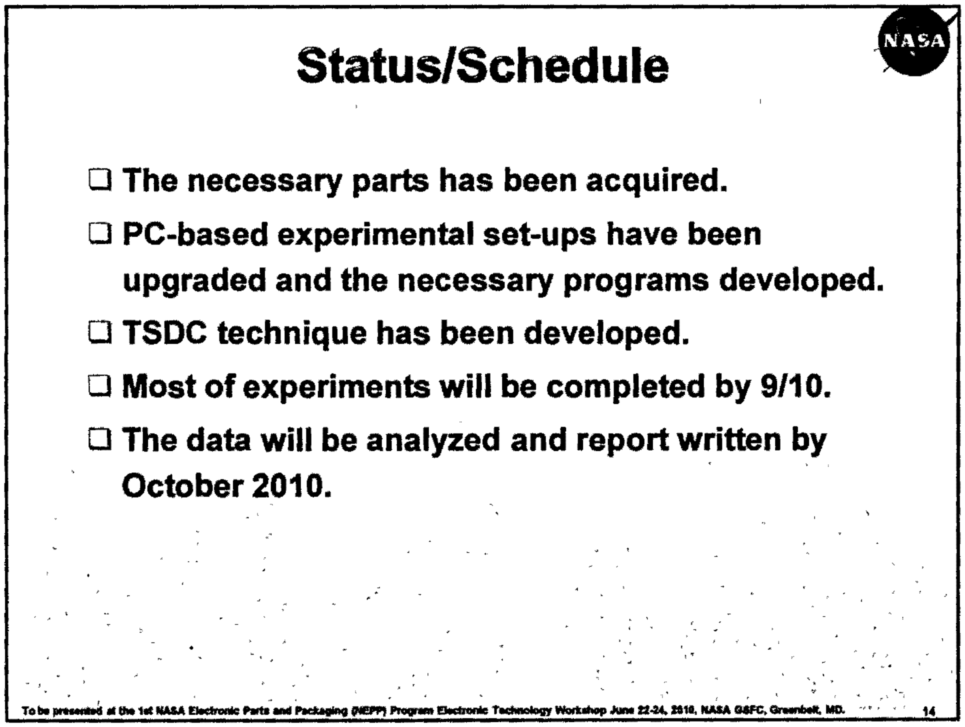
Goals for FY10

- ☐ Analyze absorption and leakage currents in tantalum capacitors. Develop simulation models and determine selection criteria.
- ☐ Investigate degradation of leakage currents under reverse bias.
- ☐ Analyze behavior of oxygen vacancies in Ta_2O_5 dielectric of solid tantalum capacitors using HALT and TSD techniques.
- ☐ Discuss derating conditions.
- ☐ Recommend BI conditions at different temperatures using simulation models.
- ☐ Present results at CARTS and ECTC, publish three papers.



Expected Impact to Community

- ☐ **Screening and Qualification**
  A system of tests to select and qualify solid chip tantalum capacitors for high-reliability applications has been suggested.
- ☐ **Using HALT**
  Accelerated life testing at high voltages and temperatures can be used to assure quality for critical systems.
- ☐ **Assembly**
  Bake before soldering might eliminate package fractures.
- ☐ **Analysis of anomalies**
  Accumulated statistical data and techniques can be used for comparative assessment of quality of capacitors in case of anomalies or failures.
- ☐ **New Technologies**
  Developed methodology allows for assessment and qualification of new technologies for space applications.



Status/Schedule

- ☐ **The necessary parts has been acquired.**
- ☐ **PC-based experimental set-ups have been upgraded and the necessary programs developed.**
- ☐ **TSDC technique has been developed.**
- ☐ **Most of experiments will be completed by 9/10.**
- ☐ **The data will be analyzed and report written by October 2010.**

Highlights/Accomplishments

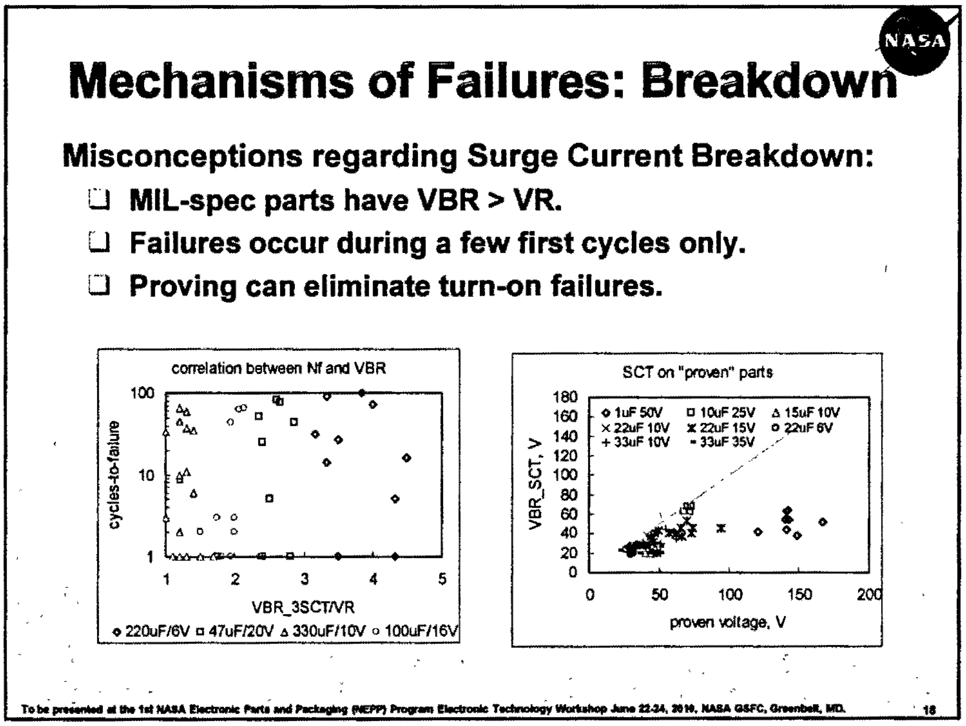
- ☐ Experimental techniques for characterization of tantalum capacitors including step stress surge current testing , scintillation breakdown testing, monitored HALT, and TSDC have been developed.
- ☐ Failures in solid tantalum capacitors – under surge current and steady-state conditions have been studied and relevant physical mechanisms suggested.
- ☐ Drawbacks in the existing requirements for S&Q have been analyzed and new test procedures have been recommended.
- ☐ Based on characterization of multiple lots of military and commercial parts a baseline for quality assessment of new technologies has been developed.
- ☐ Results of this study have been published in 9 papers in IEEE Transactions, Proceedings of CARTS, WOLTE and ECTC.

Plans (FY10/11)

Based on the Physics-of-Failure approach, developed methodology, and accumulated baseline data for solid manganese oxide tantalum capacitors evaluate quality and reliability of new technology electrolytic capacitors including:

- ☐ **Hermetic and chip high-voltage polymer capacitors**
- ☐ **Niobium oxide solid chip capacitors**
- ☐ **Micro-package capacitors**
- ☐ **Advanced wet tantalum capacitors**

Backup slides



Mechanisms of Failures: Breakdown

Misconceptions regarding Surge Current Breakdown:

- ☐ MIL-spec parts have VBR > VR.
- ☐ Failures occur during a few first cycles only.
- ☐ Proving can eliminate turn-on failures.

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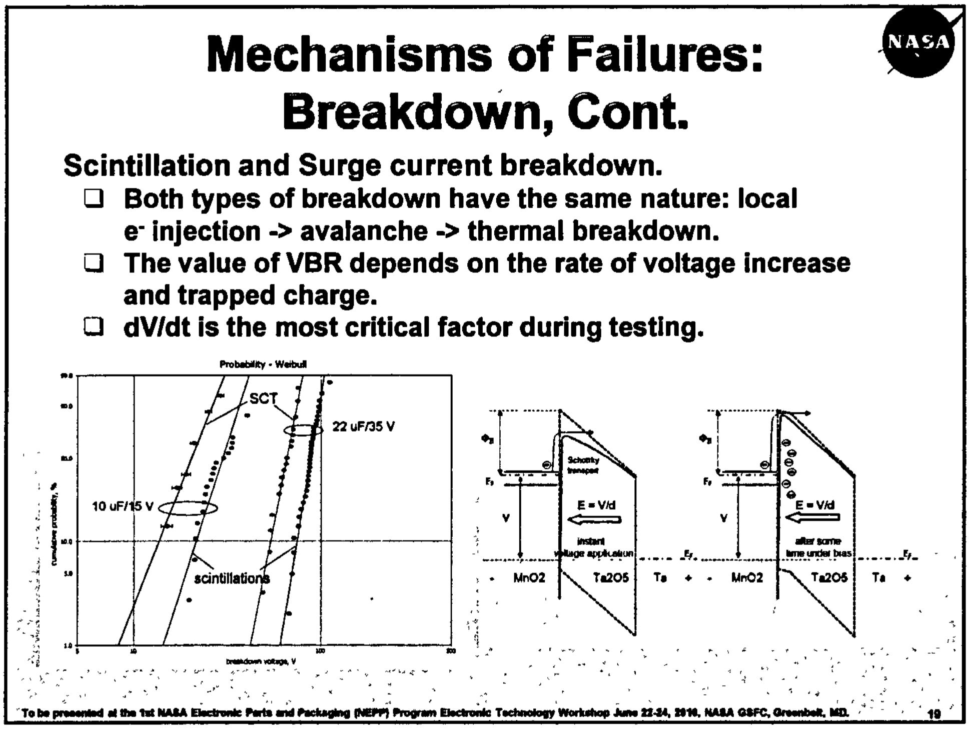
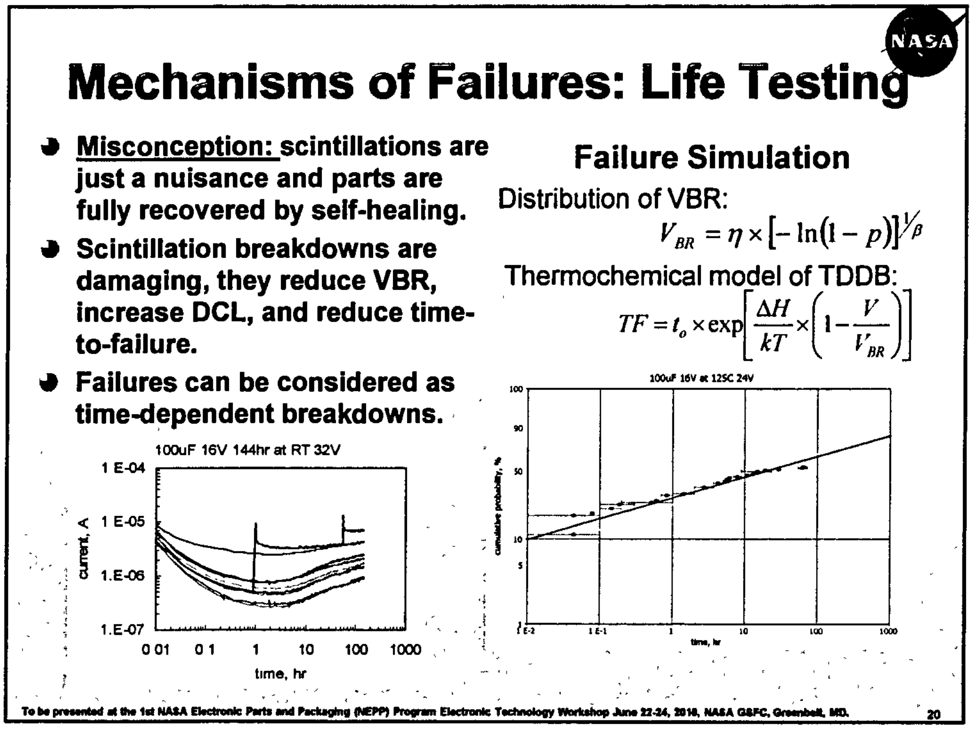


Mechanisms of Failures: Breakdown, Cont.

Scintillation and Surge current breakdown.

- ☐ **Both types of breakdown have the same nature: local e^- injection -> avalanche -> thermal breakdown.**
- ☐ **The value of VBR depends on the rate of voltage increase and trapped charge.**
- ☐ **dV/dt is the most critical factor during testing.**



Mechanisms of Failures: Life Testing

- **Misconception: scintillations are just a nuisance and parts are fully recovered by self-healing.**
- **Scintillation breakdowns are damaging, they reduce VBR, increase DCL, and reduce time-to-failure.**
- **Failures can be considered as time-dependent breakdowns.**

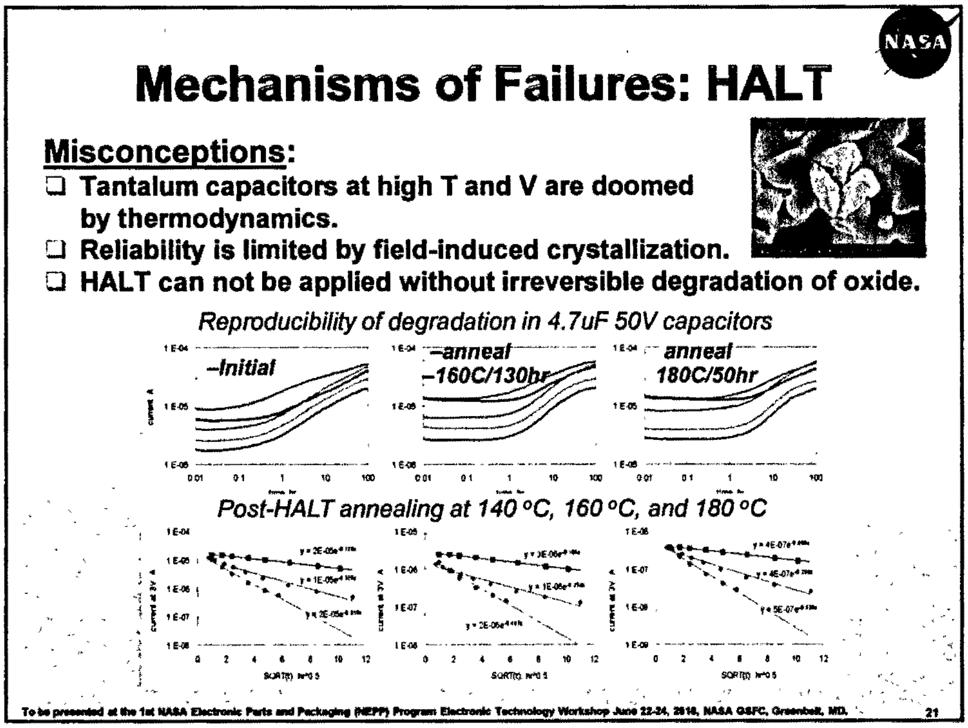
Failure Simulation

Distribution of VBR:

$$V_{BR} = \eta \times \left[-\ln(1-p)\right]^{1/\beta}$$

Thermochemical model of TDDB:

$$TF = t_o \times \exp\left[\frac{\Delta H}{kT} \times \left(1 - \frac{V}{V_{BR}'}\right)\right]$$



Mechanisms of Failures: HALT

Misconceptions:

- ☐ Tantalum capacitors at high T and V are doomed by thermodynamics.
- ☐ Reliability is limited by field-induced crystallization.
- ☐ HALT can not be applied without irreversible degradation of oxide.

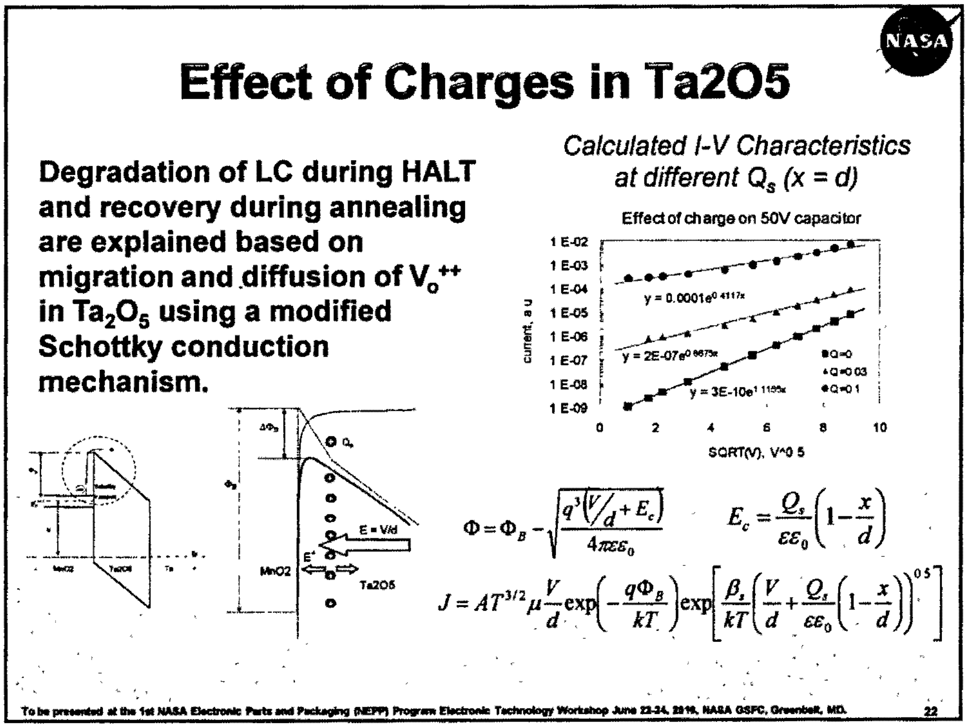
Reproducibility of degradation in 4.7uF 50V capacitors

–Initial

–anneal –160C/130hr

anneal 180C/50hr

Post-HALT annealing at 140 °C, 160 °C, and 180 °C



Effect of Charges in Ta2O5

Degradation of LC during HALT and recovery during annealing are explained based on migration and diffusion of V_o^{++} in Ta_2O_5 using a modified Schottky conduction mechanism.

Calculated I-V Characteristics at different Q_s (x = d)

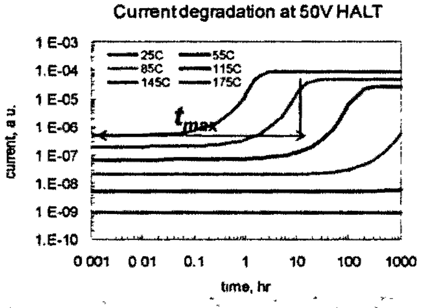
$$\Phi = \Phi_B - \sqrt{\frac{q^3\left(V/d + E_c\right)}{4\pi\varepsilon\varepsilon_0}} \qquad E_c = \frac{Q_s}{\varepsilon\varepsilon_0}\left(1-\frac{x}{d}\right)$$

$$J = AT^{3/2}\mu\frac{V}{d}\exp\left(-\frac{q\Phi_B}{kT}\right)\exp\left[\frac{\beta_s}{kT}\left(\frac{V}{d}+\frac{Q_s}{\varepsilon\varepsilon_0}\left(1-\frac{x}{d}\right)\right)^{0.5}\right]$$

Simulation of Degradation

The model allows for simulation of current degradation for different concentrations of V_o^{++}, Q_s, and mobility $\mu(T)$.

Simulation at $Q_s = 0.1\ C/m^2$, $\mu_{io} = 8.9E\text{-}3\ cm^2/V\_sec$ and $U = 1.1\ eV$



Time to stabilization, t_{max}

$$\mu_i = \frac{d^2}{t_{\max} V}$$

Current ratio, n:

$$n = \frac{J_{\max}}{J_0} = \exp\left[\frac{\beta_s}{kT}\left(\left(\frac{V}{d} + \frac{Q_s}{\varepsilon\varepsilon_0}\right)^{0.5} - \left(\frac{V}{d}\right)^{0.5}\right)\right]$$

Failures under Steady State Conditions

- **Probability of failure:**

$$P = P_{def} \times P_{deg}$$

P_{def} – probability of having a defect in Ta2O5;
(correlates with the probability of breakdown voltage).

P_{deg} – probability of current degradation.
(correlates with concentration and mobility of oxygen vacancies).

- **To assure reliability of tantalum capacitors:**
  - ☐ Safety breakdown margin control;
  - ☐ Low level of current degradation and/or low TSDC peak.