2017 NEPP Tasks Update for Ceramic and Tantalum Capacitors

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List of Acronyms

AF	acceleration factor	MLCC	multilayer ceramic capacitor
BME	base metal electrode	MOR	modulus of rupture
DCL	direct current leakage	PME	precious metal electrode
ESR	Equivalent series resistance	QA	quality assurance
FPGA	field-programmable gate array	RB	reverse bias
HALT	highly accelerated life testing	S&Q	screening and qualification
HT	High temperature	SMT	surface mount technology
HTS	high temperature storage	TC	temperature cycling
IDC	inter-digitated capacitor	VH	Vickers hardness
IFT	Indentation Fracture Test	WTC	wet tantalum capacitor

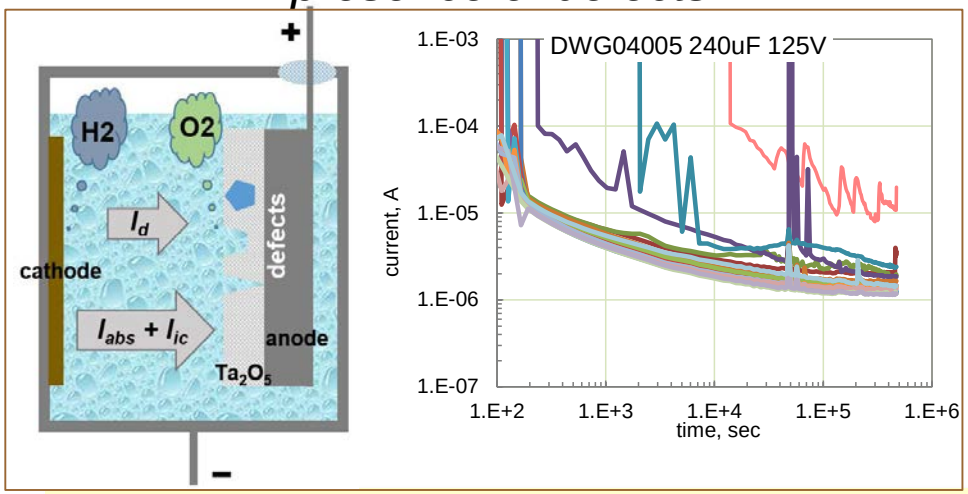
Outline

- Update on tantalum capacitors.
  - Leakage currents, gas generation and case deformation in wet tantalum capacitors.
  - MnO2 chip capacitors:
    - ESR degradation.
    - Acceleration factors for DCL degradation and failures.
    - Effect of moisture on degradation of reverse currents.
  - Polymer capacitors.
  - Future work.
- Update on ceramic capacitors.
  - Mechanical properties of MLCCs.
  - Failures in BME capacitors with defects.
  - Effect of cracking on degradation of MLCCs at HT.
  - Future work.

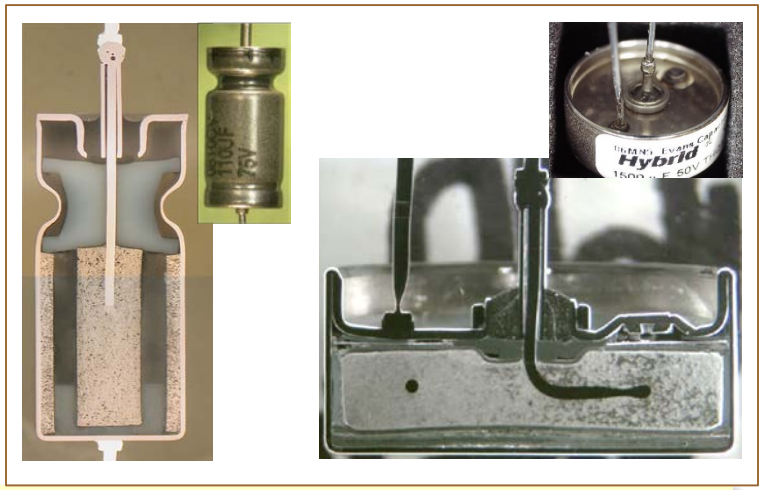
Leakage Currents, Gas Generation and Case Deformation in Wets

- NEPP report (https://nepp.nasa.gov/) contains:
  - Part I. Analysis of leakage currents;
  - Part II. Gas generation, hermeticity, and pressure in the case.
  - Part III. Electrolyte at the glass seal.
  - Part IV. Deformation of cases in high capacitance value wet tantalum capacitors.

Anomalies in leakage currents indicate presence of defects

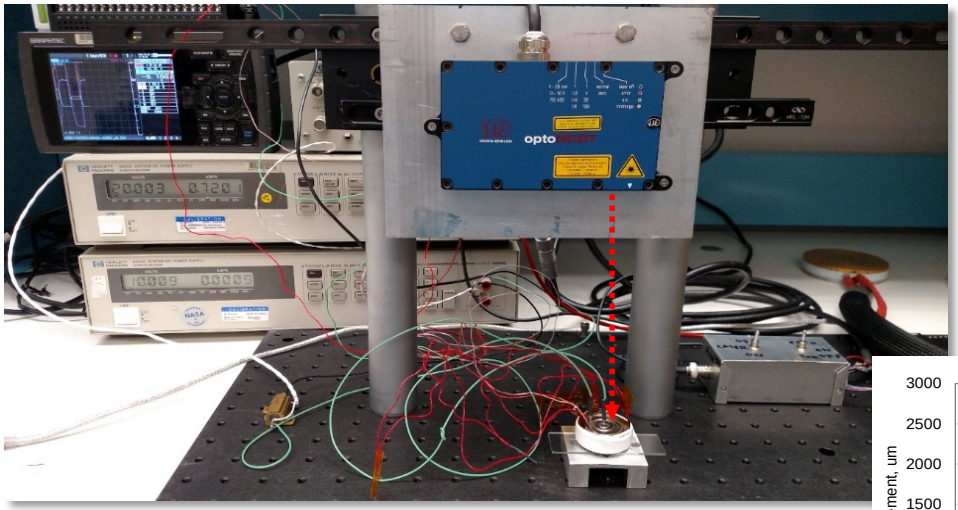


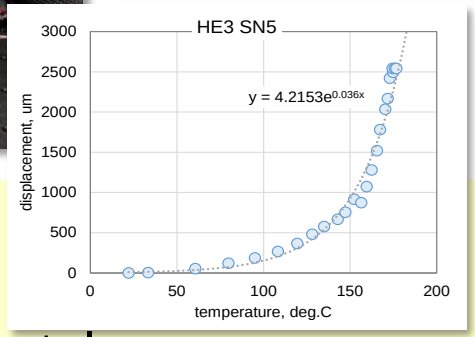
WTCs with different types of internal seals

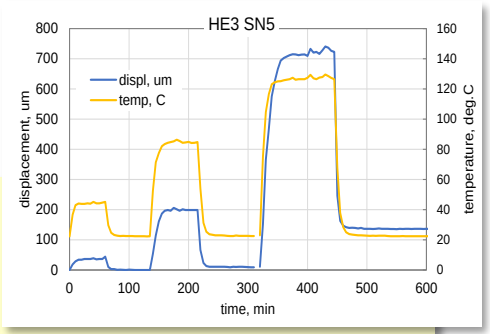


- ✓ Risks of internal leaks: non-oxidized surfaces; corrosion of welds; excessive leakage currents and gas generation.
- ✓ To reduce failures a special conditioning at HT is recommended.

Leakage Currents, Gas Generation and Case Deformation in Wets, Cont'd





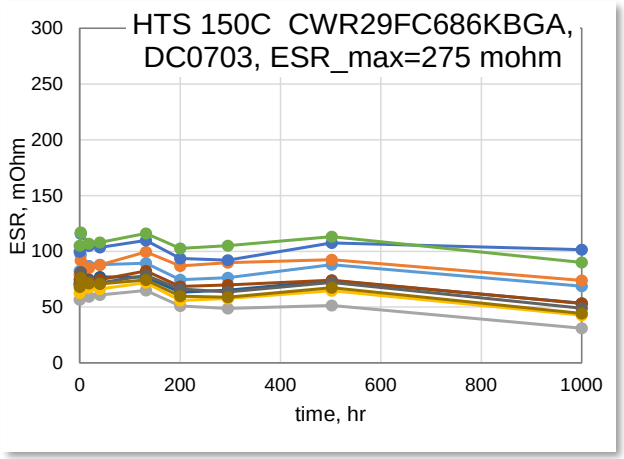


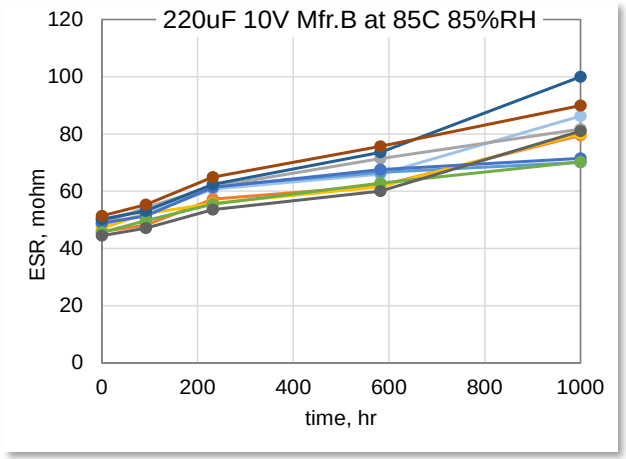
- ✓ Multiple (1650) transients did not cause case bulging likely due to H_2 outdiffusion through tantalum case.
- ✓ TC can result in irreversible lid deformation and excessive DCL.
- ✓ To assure reliable operation in vacuum, HTS testing at 150 ºC for 1000 hours is recommended.
- ✓ Glass seal protection in button case capacitors is less effective compared to the cylinder case parts.

ESR Degradation in MnO2 Capacitors

A report (https://nepp.nasa.gov/) includes analysis of environmental factors: vacuum, high temperature storage, temperature cycling, moisture, and soldering.

Examples of ESR variations during HTS and humidity testing





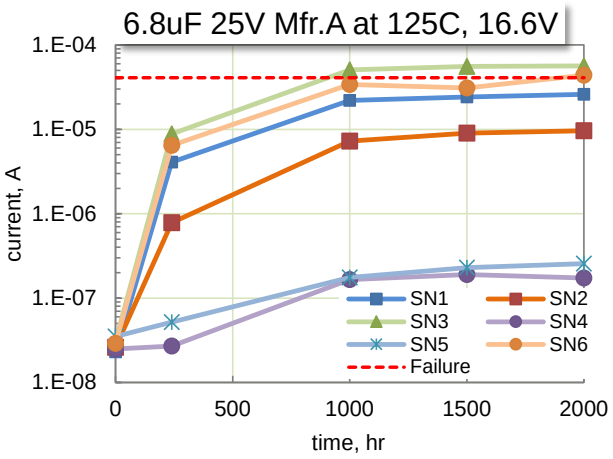
- ✓ Most parametric ESR failures are due to insufficient margin to ESR_{limit}.
- ✓ MnO2 caps can withstand 1000 hr at 150 °C and at 85 °C/85% RH.
- ✓ AEC-Q200 requirements are much more severe compared to M55365.
- ✓ Compressive stresses after bake reduce delaminations and squeeze microcracks in cathode layers resulting in reduction of ESR.
- ✓ Swelling of MC and stress relaxation in moisture have opposite effects.

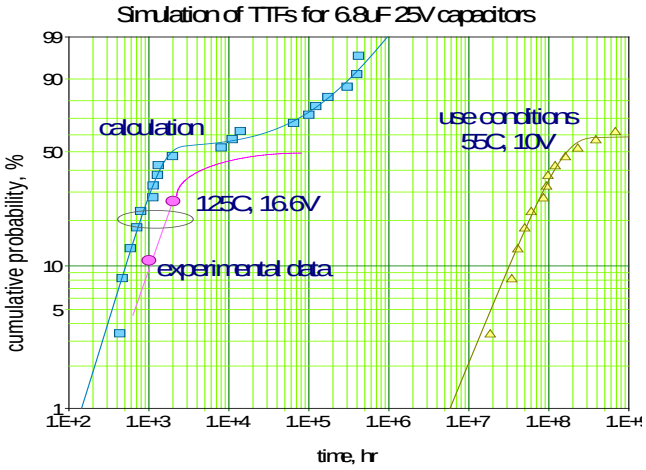
Acceleration Factors for DCL Degradation and Failures

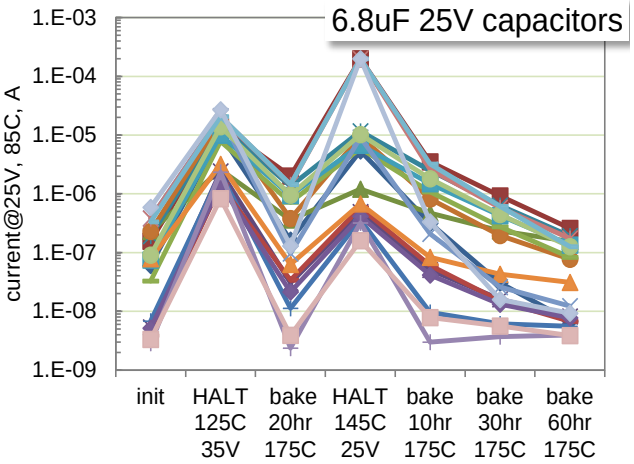
A report (https://nepp.nasa.gov/) describes catastrophic and parametric failures in Ta capacitors, their mechanisms and AF.

$$AF_V = \exp\left[B \times \left(\frac{V_{test}}{VR} - 1\right)\right]$$

$$AT_T = \exp\left[-\frac{E_a}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$







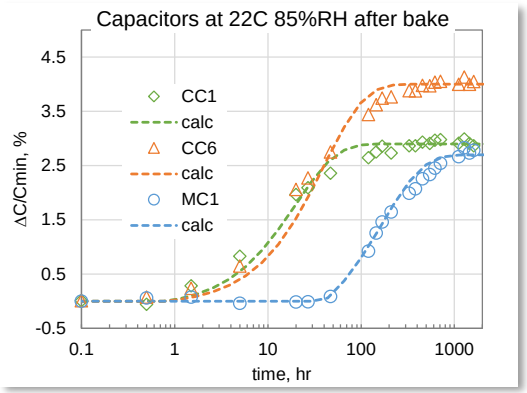
- ✓ Analysis showed that $5.5 < B < 10.3$, $1.42 < E_a < 1.66$ eV.
- ✓ Parametric degradation is reversible and can be annealed at HT.
- ✓ The mechanism of degradation is attributed to migration of oxygen vacancies in the dielectric with E ~1.1 eV.

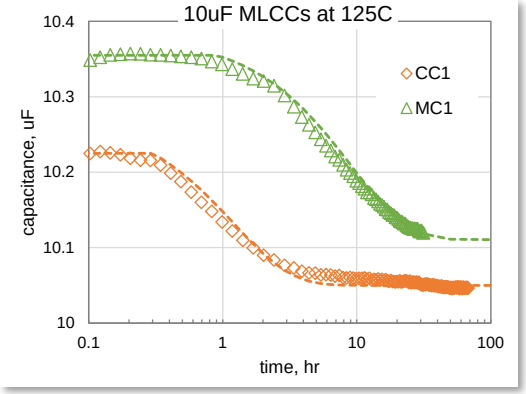
Kinetics of Moisture Sorption in MnO2 Capacitors

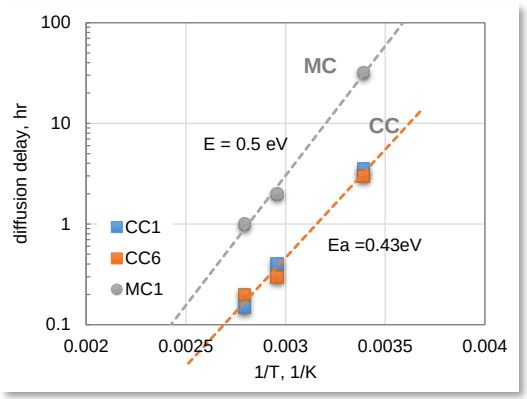
Moisture sorption can be characterized by two time constants

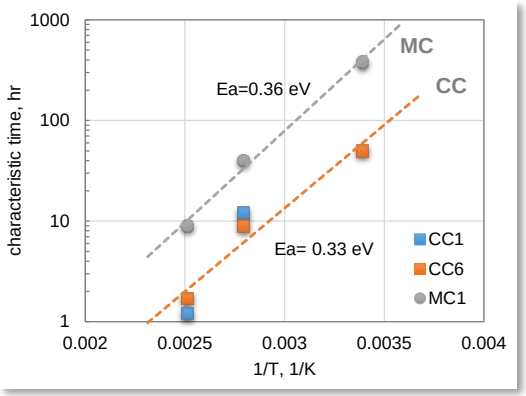
$$C(t) = C_{\min} + (C_{\max} - C_{\min}) \times \left[1 - \exp\left(-\frac{(t - t_D)}{\tau}\right)\right]$$

$$t_D = \frac{d^2}{6 \times D} \qquad \tau = \frac{d}{\gamma \times \tilde{p} \times S}$$





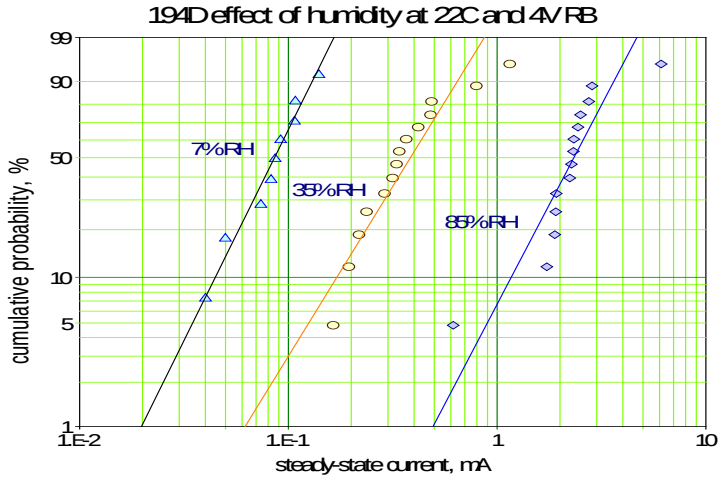


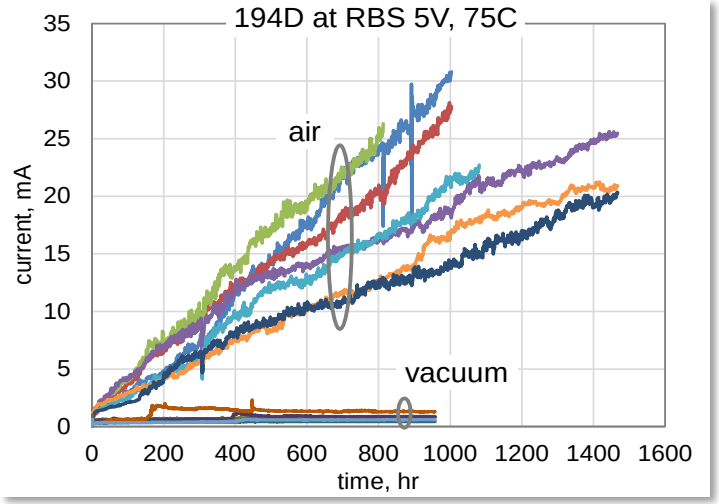


- Slugs in tantalum chip capacitors can be used as moisture sensors.
- A model for *C-t* variations has been developed.
- Bake-out times can be selected based on the characteristic times of the desorption process.

Effect of Moisture on Degradation of Reverse Currents in MnO2 Capacitors

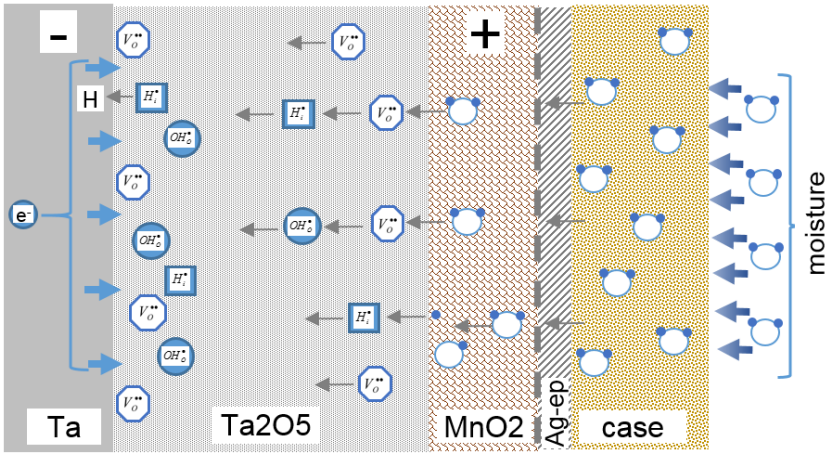
RBS of 10uF 25V capacitors





$$H_2O + V_O^{\bullet\bullet} \longrightarrow 2H_i^{\bullet} + O_O^x$$

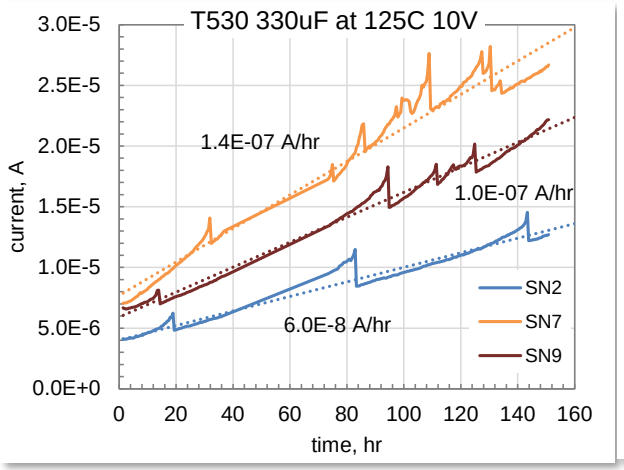
$$H_2O + V_O^{\bullet\bullet} + O_O^x \longrightarrow 2OH_O^{\bullet}$$

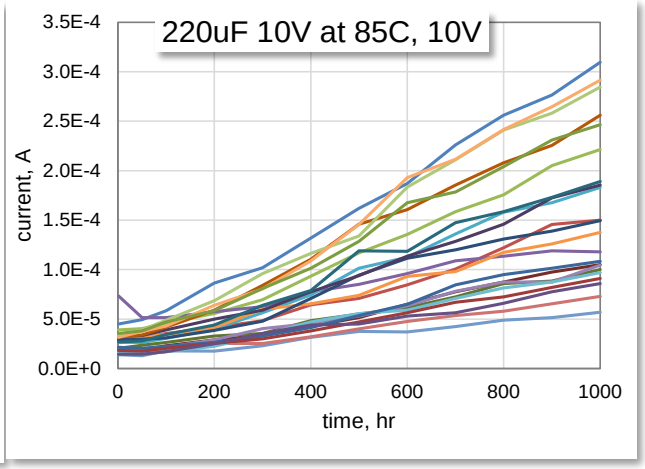


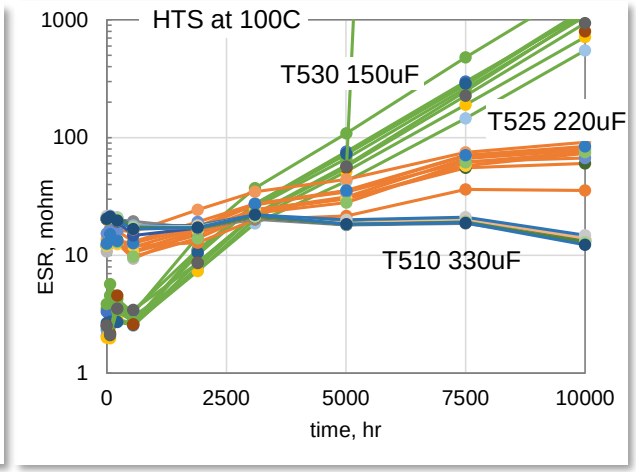
- ✓ Degradation under RB strongly depends on presence of moisture in environments and preconditioning.
- ✓ Oxygen vacancies play important role in formation of protonic species.

Polymer Capacitors

Report “Evaluation of 10V chip polymer tantalum capacitors…” (https://nepp.nasa.gov/) describes issues with low-voltage parts.



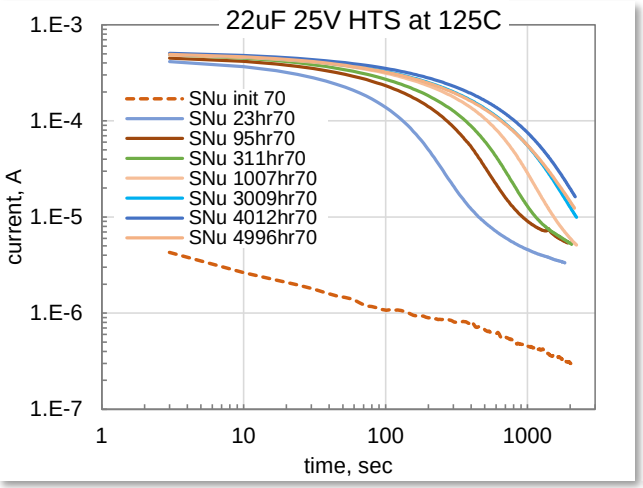


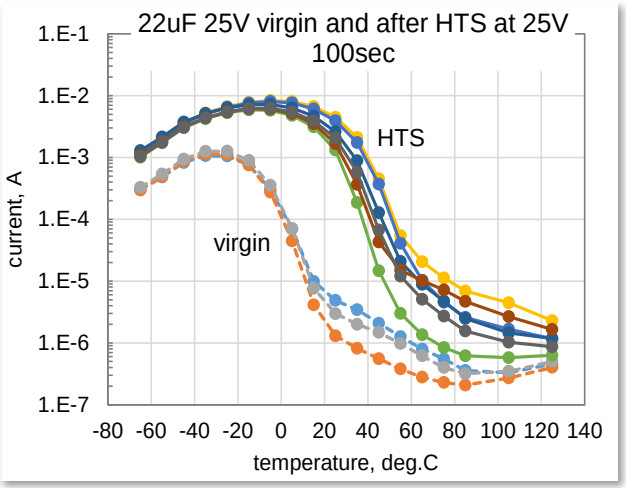


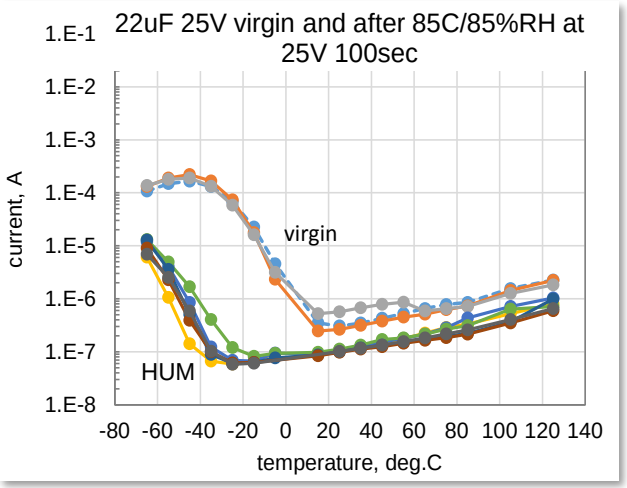
- ✓Parametric failures are likely to be major issues with polymer caps.
- ✓QA system developed for MnO2 capacitors is not applicable.
- ✓Unstable leakage currents that might be more significant in vacuum.
- ✓Significant degradation of ESR during HTS.

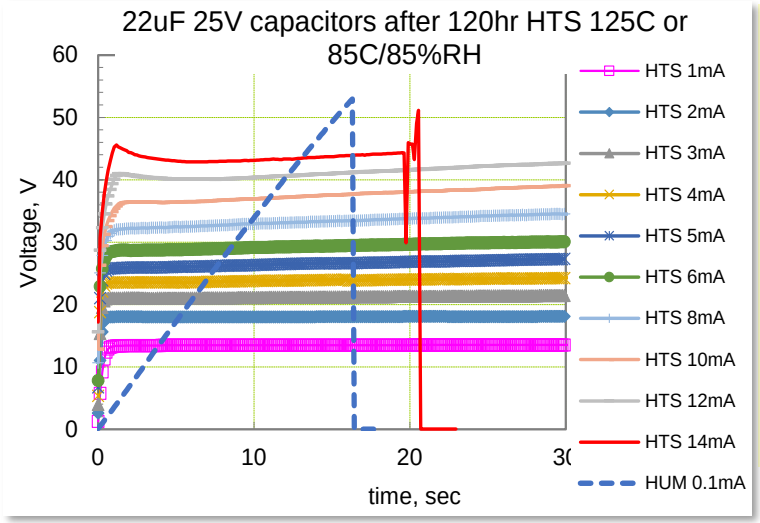
Polymer Capacitors, Cont'd

One of the most intriguing problems: anomalous transients after HTS









- ✓ Moisture plays an important role in the mechanism of transients.
- ✓ Anomalies in long-term transient currents might be due to changes in the trap system of Ta2O5.
- ✓ More analysis necessary.

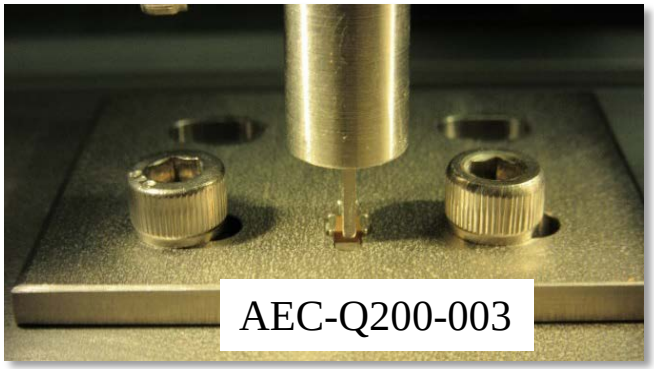
Future Work on Tantalum Capacitors

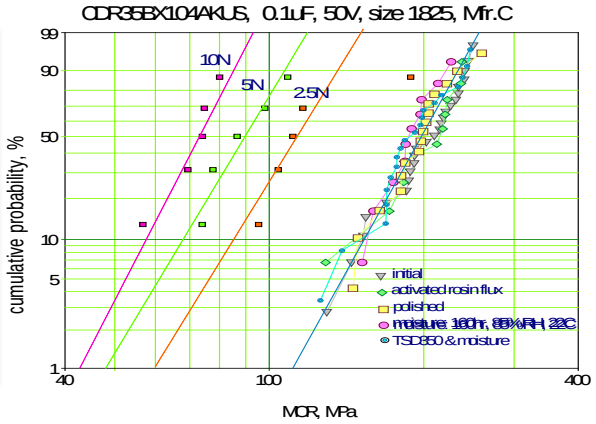
- MnO2 chip capacitors.
  - Complete current tasks.
  - Reliability acceleration factors for automotive grade capacitors.
- Advanced wet capacitors.
  - Effect of HT storage on performance and reliability.
  - Evaluation of SMT wet tantalum capacitors.
- Polymer capacitors.
  - Degradation models for HTS and recommendations for S&Q.
- Super-capacitors for space application.

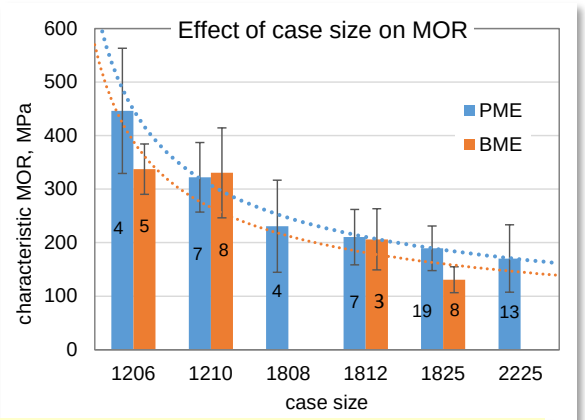
Mechanical Properties of MLCCs

- Can mechanical characteristics predict robustness of MLCCs under soldering stresses?
- Report that is available at https://nepp.nasa.gov/ includes:
  - Flexural Strength Testing of MLCCs.
  - Vickers Hardness Testing.
  - Indentation Fracture Test (IFT).

Modulus of rupture $$MOR = \frac{3FL}{2bd^2}$$



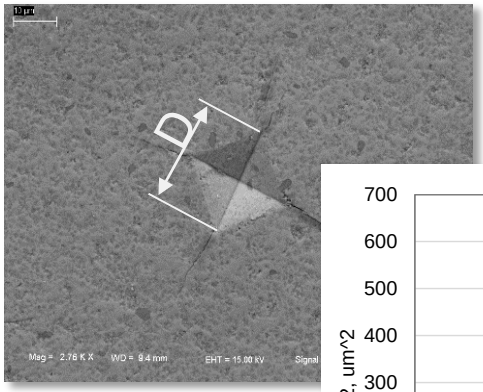




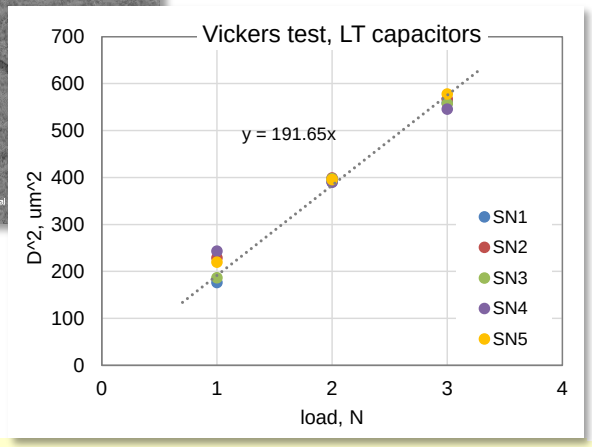
- ✓ Flexural strength method determines tensile strength at the surface.
- ✓ No substantial difference between mechanical characteristics of BME and PME capacitors.
- ✓ Smaller size MLCCs have greater strength – Benefits of BMEs.
- ✓ Same size capacitors can be used for comparative analysis of the lots.
- ✓ Variations of MOR values from lot to lot might exceed 50%.

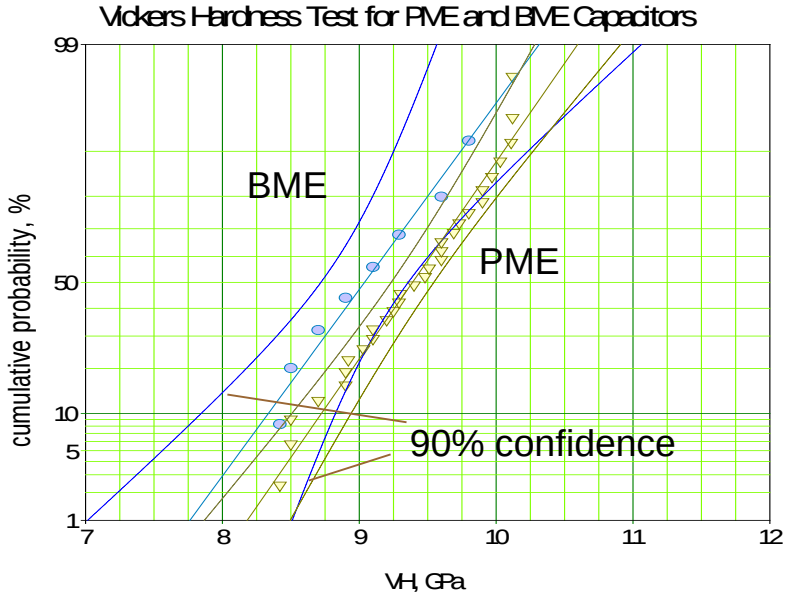
Vickers Hardness

- Hardness is a resistance to indentation.



$$VH = \frac{1.854 \times P}{D^2}$$

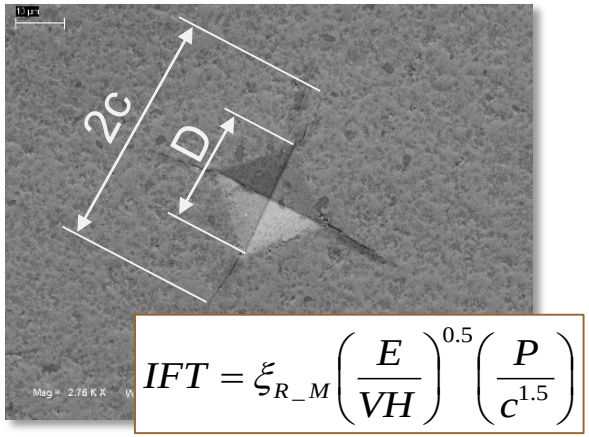


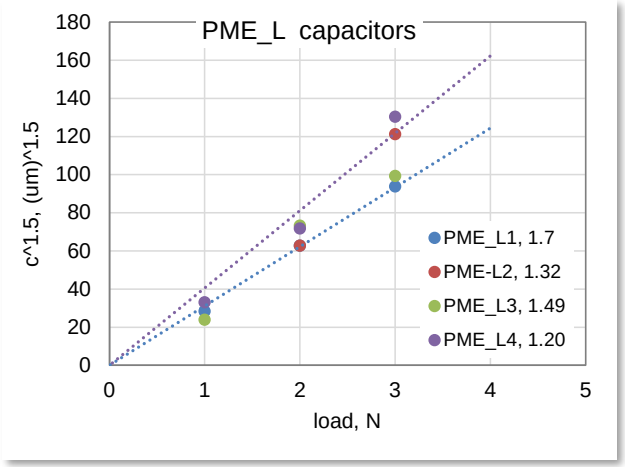


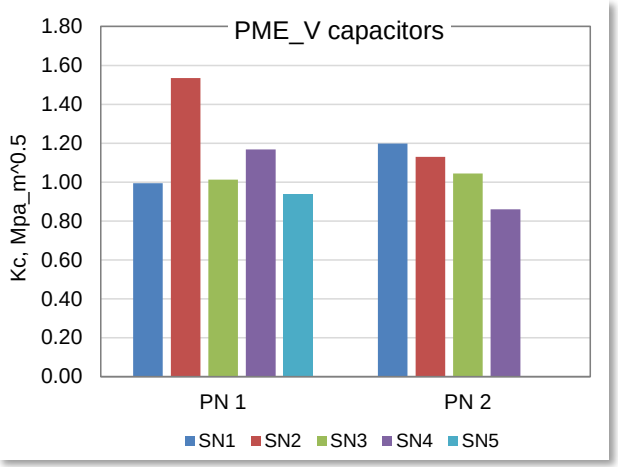
- ✓ In-situ VH measurements are possible using MLCCs with relatively thick cover plates. *P* should be low so the depth of the indentation is < 2x the thickness of the cover plate.
- ✓ No significant difference between PME and BME capacitors.
- ✓ Improvements to reduce errors might allow for revealing differences in lots.

Indentation Fracture Test

- Fracture Toughness: the ability of a material to withstand stresses in the presence of cracks.
- IFT technique is the most controversial.



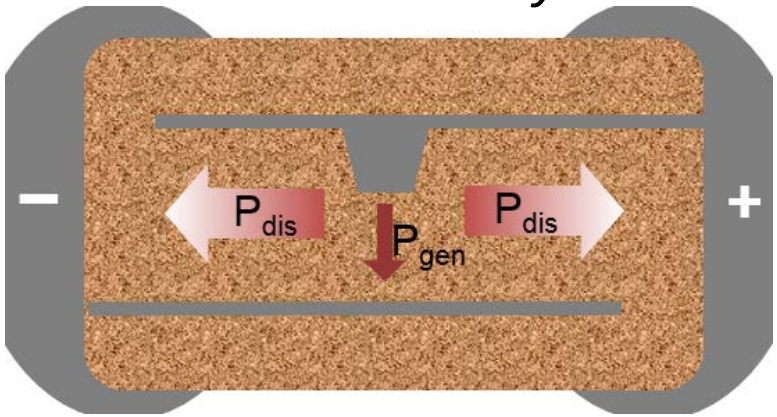




- ✓ IFT can provide useful information regarding robustness of capacitors under soldering conditions, but additional analysis is necessary.
- ✓ Mechanical testing might be useful for selecting robust parts for manual soldering, but more work is necessary to reduce errors and select criteria.
- ✓ For critical applications a combination of assembly simulation and special testing might be recommended.

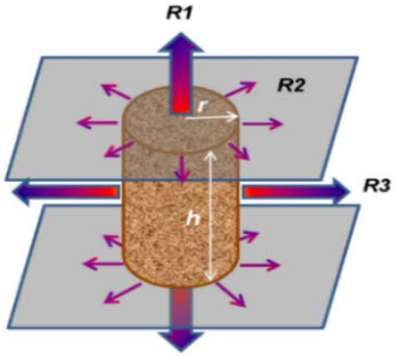
Failures in BME Capacitors with Defects

Thermal run-away model



$$C \times \frac{dT}{dt} = I_d \times V - \frac{T - T_0}{R_\theta}$$

$$I_d = \pi \times r^2 \times J_d(T, E_d, \Phi_B)$$



$$J_S = AT^{3/2}\mu E \exp\left(-\frac{\Phi_B}{kT}\right)\exp\left(\frac{\beta_s E^{0.5}}{kT}\right)$$

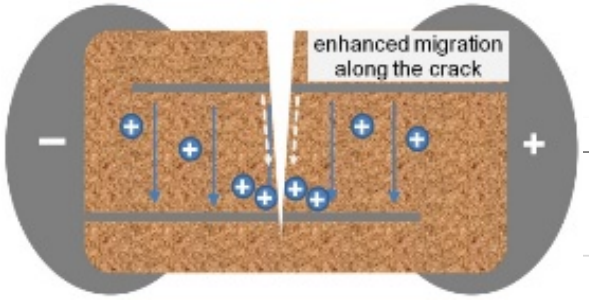
- Migration of V_O^{++} is enhanced either by increased *E*, as in case of thinning of the dielectric, or by increased μ, as in case of cracks.
- Catastrophic failures occur when Φ_B decreases to Φ_{Bcr}. For capacitors having small, micrometer-size defects Φ_{Bcr} is low so catastrophic failures are unlikely.
- In the range of typical HALT conditions voltage increases the probability of catastrophic failures to a greater degree compared to temperature. This might result in errors in AFs.

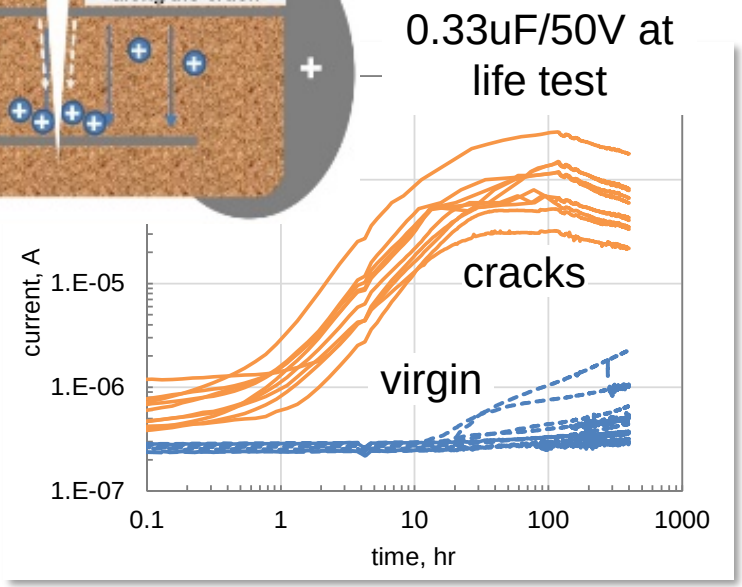
Effect of Cracking on Degradation of MLCCs at HT

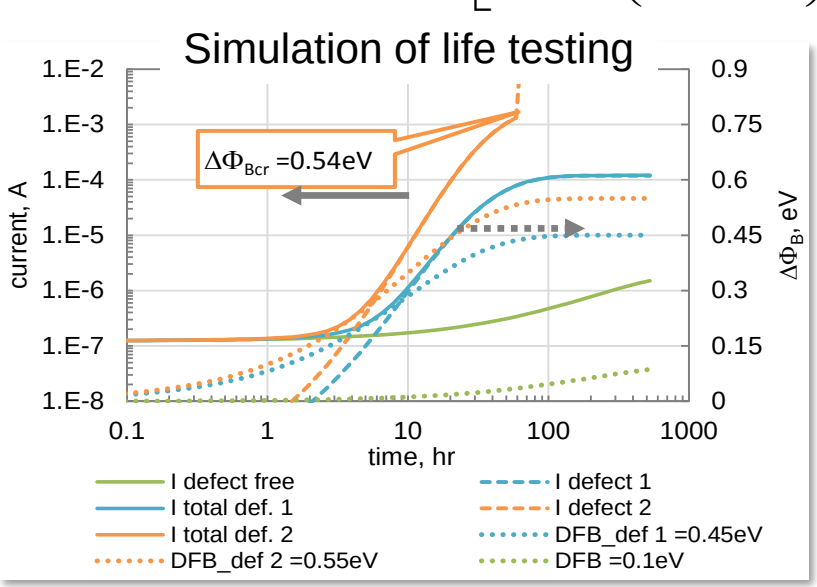
Stretched exponential dependence of Φ_B with time.
In bulk: τ_V = 200 hr, (μ_V ~5×10^{-15} cm^2/Vs)
Along the crack: τ_c ~10 hr (μ_V ~10^{-13} cm^2/Vs).

$$\tau_V = \frac{0.78 \times d^2}{\mu_V \times V}$$

$$\Phi_B(t) = \Delta\Phi_B \times \left[1 - \exp\left(-\left(\frac{t}{\tau_V}\right)^{\gamma}\right)\right]$$

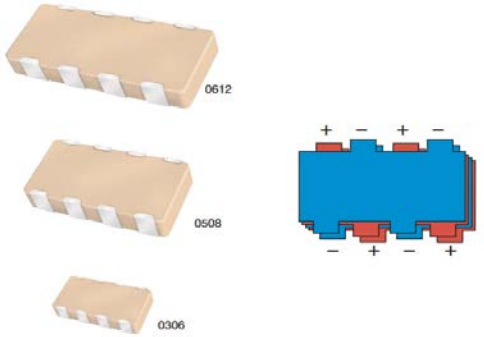






- ✓Model: accelerated migration of V_O^{++} along the cracks.
- ✓Simulations are in reasonable agreement with experimental data.

Future Work on Ceramic Capacitors



- Evaluation of IDC capacitors used for FPGAs.
- Comparative analysis of performance and reliability of BME and PME capacitors.
  - Breakdown voltages.
  - Analysis of failures in BME capacitors with defects.
  - Express testing to determine reliability acceleration factors for BME capacitors.
  - Guidelines for selecting “auto” MLCCs for different project levels.